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CRISIS DYNAMICS AND STRATEGIC DECISION

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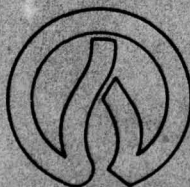
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Although timing and dynamic variables are generally acknowledged as essential aspects of crisis analysis, they are not explicitly included in current crisis models, which remain static in nature. Most often, models of the decision making process assume timing to be a characteristic of a crisis situation, rather than a variable in the model itself. Examination of any number of recent crises reveals timing to be so fundamental to the decision process, and the nature of the actions ultimately taken, that it

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becomes clear any attempt to accurately model this decision process requires an explicit inclusion of time and its impact on critical variables.

The present report revises the classical model of deterrence, which is the basis of many models currently in use, to incorporate dynamic variables previously excluded from the analysis. This revised model of deterrence, incorporating dynamic elements, is then utilized to develop a basic computer program and related graphics display designed to summarize the status of the relationship between a pair of nations and the potential for conflict.

The model developed in the present research revises the classical approach in several important respects. First, the nations involved are no longer dichotomized as a potential aggressor and deterrer. Rather, each party is characterized as viewing the other as a potential aggressor. Thus the analysis is no longer restricted to a one-sided optimization problem, but can be considered as a game-theoretic situation.

Each of the parties in the analysis must choose its course of action under a condition of uncertainty about the other party's preferences and likely actions. The possibility that the other nation will itself attack, not only out of self-interest but also due to a fear of an impending first strike, is also incorporated into the model, enabling it to deal with the option of preemptive attacks. A further refinement incorporates the possibility that one nation will attack the other as a result of apprehension that the other will engage in a preemptive strike.

This revised model is then utilized in an interactive computer program which monitors the changes in several of the critical variables in the decision calculus of each nation in the analysis and its national command authority over time. Because of the difficulties inherent in determining utilities with any degree of precision, the program as currently implemented does not estimate any expected utilities. The program and related graphics presently focus on the probability estimates of respective national leaders, that an opposing nation will engage in hostilities, and the rate of change in these estimates over time.

PREFACE

It is possible to trace the development of crisis analysis and crisis management in the modern era from the major international crises which have confronted the United States, such as Pearl Harbor and the Cuban Missile Crisis, through the inquiry efforts which followed and subsequent efforts to improve our national ability to monitor international events, predict potential areas of conflict and manage ongoing events to deter warfare. Such analyses have, increasingly, moved from historical and journalistic accounts toward more theoretically based efforts to analyze crisis situations, and automated tools which will enable key decision makers to maximize their ability to deal with critical crisis problems.

The present effort falls into the general area of basic crisis research, and considers the essential element of timing in deterrence situations. Working toward the aim of providing a more realistic framework upon which to assess the the actions of individual actors in crisis situations, the present research expands upon some traditional notions of deterrence theory, and develops a dynamic approach to the deterrence situation. A related document and associated materials provide a computer program implementing these findings.

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EXECUTIVE SUMMARY

The general area of strategic decision making, and crisis management in particular, has become increasingly sensitive in recent years both to timing and the sequence of decisions which serve to shape crisis outcomes. In large part, it is possible to attribute this change to major advances in technology, such as in the critical C^3 areas, with the net result being the case that international crises take place in ever shorter time spans, with time itself being a significant factor in the decision process.

As crises unfold in varying time frames, specific demands are placed on a nation's intelligence and early warning capabilities, its National Command Authority, the readiness posture of its military forces, and the C^3 functions of its defense establishment. Such developments and requirements serve to underline the importance of understanding the essential dynamic elements in crisis decision making, and the impact which they are likely to have on those faced with difficult crisis decisions.

Although timing and dynamic variables are generally acknowledged as essential aspects of crisis analysis, they are not explicitly included in current crisis models which remain static in nature. Most often, models of the decision-making process assume timing to be a characteristic of a crisis situation, rather than a variable in the model itself. Examination of any number of recent crises reveals timing to be so fundamental to the decision process, and the nature of the actions ultimately taken, that it becomes clear any attempt to accurately model this decision process requires an explicit inclusion of time and its impact on critical variables.

The present report revises the classical model of deterrence, which is the basis of many models currently in use, to incorporate dynamic variables previously excluded from the analysis. This revised model of deterrence, incorporating dynamic elements, is then utilized to develop a basic computer program and related graphics display designed to summarize the status of the relationship between a pair of nations and the potential for conflict.

Specifically, the classical model of deterrence and its variants assume both a potential aggressor and deterrer that are rational actors in the game-

theoretic sense. The potential aggressor is faced with a choice between the status quo, if he does not initiate an attack, and a "lottery" between victory and defeat if the choice is made to initiate such an attack. The deterrer's only role is to issue threats and engage in other actions in an attempt to persuade the potential aggressor not to attack, and respond in the event that such deterrence fails.

Whether the actions of the deterrer will be successful in deterring an attack, and maintaining the status quo, will depend on at least four factors:

o   the potential aggressor's gains if he achieves his objectives;

o   the potential aggressor's perception of the probability that he will achieve these objectives through an attack;

o   the losses which a potential aggressor will suffer in the event an attack is unsuccessful and defeated following an attack; and

o   the attitude of a potential aggressor toward risk.

It is essential that any crisis model developed, as in the current research, take at least these factors into account, as well as the changes which take place in them over the course of a crisis period.

The model developed in the present research revises the classical approach in several important respects. To begin, the nations involved are no longer dichotomized as a potential aggressor and deterrer. Rather, each party is characterized as viewing the other as a potential aggressor. Thus the analysis is no longer restricted to a one-sided optimization problem, but can be considered as a game-theoretic situation.

Each of the parties in the analysis must choose its course of action under a condition of uncertainty about the other party's preferences and likely actions. The possibility that the other nation will itself attack, not only out of self-interest but also due to a fear of an impending first strike, is also incorporated into the model, enabling it to deal with the option of pre-emptive attacks. A further refinement incorporates the possibility that one nation will attack the other as a result of apprehension that the other will engage in a preemptive strike.

This revised model is then utilized in a computer program, developed in the research, which monitors the changes in several of the critical variables

in the decision calculus of each nation in the analysis over time. Because of the difficulties inherent in determining utilities with any degree of precision, the program as currently implemented does not estimate any expected utility calculations. The program and related graphics presently focus on the probability estimates of respective national leaders, that an opposing nation will attack, and the rate of change in these estimates over time.

Also fundamental to the program and display are the preferences for war or peace of the individual members of the respective nations' National Command Authority. These data are subsequently utilized to define a series of warning conditions indicating the likelihood of conflict, and the time estimated as being available to prevent it.

In view of the research completed and program developed, several implications for further work emerge. First, while the model and program are currently applied in one empirical example, that of the crisis preceeding the 1967 Six Day War, further testing should be undertaken utilizing both historical examples and more current situations which have considerable crisis potential.

Second, a set of questions revolving around the utility of the probability estimates in reflecting changes in the political situation, realism of the critical values selected, and usefulness of expert panel estimations should be addressed. Finally, it is now clear that it is possible to modify the model developed and associated programming to incorporate utilities explicitly, with an aggregate utility function over the National Command Authority of each nation being derived, for each of the alternative courses of action feasible.

I. INTRODUCTION

Two of the elements most critical to defense and national security decision makers are the time frame in which the crisis develops and the sequence of decisions which determines the crisis outcome.[1] Increasingly it appears to be the case that international crises take place in ever shorter time spans, with the dynamic elements becoming a significant factor in the decision process. As crises unfold in varying time frames, specific demands are placed on a nation's intelligence and early warning capabilities, its decision making or national command authority, the readiness of its military force, and the command, control and communications functions of its defense establishment.

In view of the set of problems created for a nation's policy makers and defense leadership by crisis management within the context of limited time frames, it is important to understand the essential dynamic elements in crisis decision making, and the impact which these elements are likely to have on those faced with the difficult crisis decisions.

1.1 Dynamics in Crisis Decision Making

While the importance of the timing element is generally acknowledged as an essential aspect of crisis analysis, it implies a major assumption which is seldom explored and on which little research has been done to incorporate the dynamic element explicitly as a component of the model. Most often, models and studies of the decision making process are static in nature, assuming time to be a characteristic of the crisis situation, rather than a variable in the equation.

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[1] Compare, for example, Israel's experience in the crisis surrounding the outbreak of the 1967 Six Day War, which occupied some two weeks in May 1967, with that surrounding the outbreak of the 1973 October War, which took place in a matter of two days. See Abraham R. Wagner, *Crisis Decision-Making: Israel's Experience in 1967 and 1973* (New York: Praeger Publishers, 1974). This problem is further analyzed in R. D. McLaurin, Mohammed Mughisuddin and Abraham R. Wagner, *Foreign Policy Making in the Middle East* (New York: Praeger Publishers, 1976).

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Examination of specific crises reveals the fundamental nature of the dynamic elements, and the important relationship which time plays in the type and nature of the decisions reached and resulting actions taken. Analyzing Israeli decisions prior to the June 1967 war and the 1973 October War, for example, it is possible to identify major differences in both the decision process and decisions reached by that nation's political and military leadership. While it is clear that in the 1973 case the time frame for the dissemination and evaluation of intelligence, formulation of policy options, and selection of a course of action was far shorter than in 1967, no formal framework exists for the dynamic analysis of these differences.[2] Looking at United States and Soviet actions in various crises over the past two decades, it is possible to witness some of these same fundamental timing problems.[3]

Specifically, it is possible to identify several critical areas in the policy making process where the timing element, and a better understanding of the functional problems involved, are of major importance:

o   in the demands placed on intelligence collection, analysis and dissemination to key military and political decision makers;

o   in shaping the constraints on the nation's decision makers, such as the national command authority, National Security Council and others by the set of feasible options within the perceived time frame; and

o   in planning for essential command, control, communications (C^3) and logistic systems to deal with crisis management and potential conflict situations.

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[2] On the Israeli experience, see also Avi Shalim, "The Failure of Israeli National Intelligence Estimates," *World Politics* (Winter 1976).

[3] These factors are especially relevant to American policy decisions before and after the outbreak of the Korean conflict. See Alexander L. George and Richard Smoke, *Deterrence in American Foreign Policy: Theory and Practice* (New York: Columbia University Press, 1974), pp. 140-183.

Considering the range of crisis situations which could confront United States decision makers in Europe, the Middle East, Asia and other regions, it is possible to envision a number of situations where the decision process and its dynamic elements would be critical to the formulation of American policy options. In the opening phase of a NATO/Warsaw Pact conflict, for example, the timing of Soviet actions and U.S. responses could easily influence a Soviet choice between moderation, selective nuclear targeting, theater-level nuclear war, or implementation of a Soviet SIOP.[4]

Regardless of the region or specific situation involved, it is clear that international crises share common logical elements and present similar problems for analysis. Thus, the problem becomes a general one of specifying individual crisis elements and developing a dynamic model for the analysis of crises which includes time as a fundamental variable, rather than as a characteristic of the crisis situation. Such a dynamic model provides a formalized approach to the analysis of crisis choice situations within the context of the strategic situation perceived by the decision makers in terms of the salient variables.

By structuring the model in this fashion, it is then possible to consider:

o   changes in critical crisis variables over the time frame
        involved;

o   perceptions of such changes by key decision makers; and

o   resulting changes in the discounted, normalized utilities
        of alternative policy options and crisis strategies.

Utilizing a Bayesian approach to the determination of probabilities, the dynamic model can be programmed for purposes of computer simulation and analysis of specific empirical situations.[5] While previous efforts have yielded both

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[4]See Benjamin S. Lambeth, *United States and Soviet Doctrinal Views on Selective Nuclear Targeting* (WN-9217-DDRE)(Santa Monica: The Rand Corporation, July, 1976), and Lynn E. Davis, "Limited Nuclear Options: Deterrence and the New American Doctrine," *Adelphi Papers No. 121* (London: International Institute for Strategic Studies, 1976).

[5]See, for example, Central Intelligence Agency, *Handbook of Bayesian Analysis for Intelligence* OPR-506 (June 1975).

insights and data relevant to many of the critical problem areas, it remains for explicit dynamic elements to be added to the deterrence calculus at the formal level and applied to data on specific international events and crises.

Formal or mathematical deterrence theory, as developed and applied in a large number of studies, has sought to provide a logical framework for the analysis of crisis situations at specific points in time.[6] Employing assumptions from economic analysis, the theory postulates that the rational decision maker choses that course of action which, *ceteris paribus*, yields the highest expected utility as perceived by him, and seeks to determine the value or utility of the possible alternatives available to him in a given situation. Although static in nature, this calculus provides the basic foundation for a dynamic model.

1.2 Deterrence Theory and Crisis Analysis

As noted, the use of concepts from mathematics and economic utility theory has had a long and variegated history in the literature on international deterrence. In general, this use has been beneficial for two related reasons. First, the use of mathematical constructs has necessitated rigorous thinking about the key variables and their interrelations. Second, the use of diminished utility theory has introduced a greater degree of precision into this rigorous thinking, a precision which has lent additional clarity to discussions of empirical situations and has led to the discovery of non-obvious relationships

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[6]See Charles F. Doran, "A Theory of Bounded Deterrence," *Journal of Conflict Resolution*, 17 (1973), 2:243-269; Daniel Ellsberg, "The Crude Analysis of Strategic Choices," (P-2183)(Santa Monica: The Rand Corporation, 1969); Clifton F. Fink, "More Calculations about Deterrence," *Journal of Conflict Resolution*, 9 (1965) 1:54-65; Douglas E. Hunter, *Aspects of Mathematical Deterrence Theory* (Los Angeles: University of California Security Studies Project, 1971); S. A. Kaplowitz, "An Experimental Test of a Rationalistic Theory of Deterrence," *Journal of Conflict Resolution*, 17 (1973), 3:535-572; John E. Mueller (ed.), *Approaches to Measurement in International Relations* (New York: Appleton-Century-Crofts, 1969): John E. Mueller, *Deterrence, Numbers and History* (Los Angeles: University of California Security Studies Project, 1968); Bruce M. Russett, "The Calculus of Deterrence," *Journal of Conflict Resolution*, 7 (1963), 2:79-109; and Glenn H. Snyder, *Deterrence and Defense: Toward a Theory of National Security* (Princeton: Princeton University Press, 1961).

between variables. Nevertheless, five problem areas are evident in previous analyses which have diminished the value of the results obtained thus far.[7]

First, the concepts of utility theory that have been applied could have been used with greater conformity to other applications, such as economics, voting systems and electoral competition. In these applications, for example, it is assumed that a decision maker first ranks the logically possible outcomes of a social situation from most to least preferred, and then constructs his utility function over the outcomes.[8] On the other hand, deterrence theorists have typically moved directly from the set of outcomes to a decision maker's utility for each outcome. As a result of omitting the intermediate step (constructing preference orderings and attendant utility functions for outcomes), some theorists have generated unnecessary and confusing conceptual problems.[9]

Second, some concepts from utility theory, especially statistical decision theory, that have considerable relevance to formal deterrence theory have not

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[7] The discussion of the first two problems appears to be original to the present report. On the latter three problems, see the discussion in George and Smoke, *Deterrence in American Foreign Policy*. See also P. M. Morgan, *Deterrence, A Conceptual Analysis* (Beverly Hills: Sage Publications, 1977).

[8] A *utility function* is an assignment of real numbers to outcomes so as to reflect a decision maker's preferences and his degree of preference for one outcome over another. See Karl H. Borch, *The Economics of Uncertainty* (Princeton: Princeton University Press, 1968); John S. Chipman, "The Foundations of Utility," *Econometrica,* 28 (1960), pp. 193-224; Gerard Debreu, "Representation of a Preference Ordering by a Numerical Function," in R. M. Thrall, C. H. Coombs and R. L. Davis (eds.) *Decision Processes* (New York: John Wiley & Sons, 1954); Gerard Debreu, "Stochastic Choice and Cardinal Utility," *Econometrica*, 28 (1960); R. Duncan Luce and Howard Riaffa, *Games and Decisions* (New York: John Wiley & Sons, 1957); William H. Riker and Peter C. Ordeshook, *An Introduction to Positive Political Theory* (Englewood Cliffs: Prentice-Hall, 1973); and John Von Neumann and Oskar Morgenstern, *The Theory of Games and Economic Behavior (2nd ed.)* (New York: John Wiley & Sons, 1954).

[9] See, for example, Fink, "More Calculations about Deterrence," who corrects and refines Russett, "The Calculus of Deterrence." See also J. David Singer, *Deterrence, Arms Control and Disarmament: Toward a Synthesis in National Security Policy* (Columbus: Ohio State University Press, 1962).

been explicitly applied. These concepts relate to the problem of decision
making under conditions of risk and uncertainty. While it is true that deter-
rence theorists have paid considerable attention to the problems engendered
by risk and uncertainty, their discussions have been largely verbal and super-
ficial, and only indirectly related to the use of these concepts in statistical
decision theory. Deterrence theorists, for example, often discuss risk and
uncertainty in relation to the possible actions of a decision maker's adversary.
The decision maker, it is assumed, assesses these possible actions by estimating
specific probability numbers for each action a potential adversary might adopt.[10]
In statistical decision theory, on the other hand, it is not only assumed that
decision makers estimate specific probability numbers for actions or outcomes,
but also that they may, due to a large measure of uncertainty or imperfect in-
formation about the values of relevant variables, estimate only a range of
probability numbers in which they believe the "true" probability falls.[11]

Third, as noted by George and Smoke, a major problem in deterrence theory,
especially in analyzing past crisis situations and developing concrete, applicable
policies, has been the failure to more clearly distinguish between what they

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[10]See Ellsberg, "The Crude Analysis of Strategic Choices,"; Fink, "More
Calculations about Deterrence,"; Hunter, *Aspects of Mathematical Deterrence
Theory*; Mueller, *Deterrence, Numbers and History*; Russett, "The Calculus of
Deterrence,"; Thomas C. Schelling, *Arms and Influence* (New Haven: Yale Univer-
sity Press, 1966); Singer, *Deterrence, Arms Control and Disarmament*; and
Snyder, *Deterrence and Defense*.

[11]For applications of these concepts to voting systems and electoral com-
petition, see Alvin Rabushka and Kenneth A. Shepsle, *Politics in Plural Societies,
A Theory of Democratic Instability* (Columbus: Charles E. Merrill, 1972); Kenneth
A. Shepsle, "Essays on Risky Choice in Electoral Compeition," Ph.D. dissertation
(Rochester: University of Rochester, 1970); Kenneth A. Shepsle, "Parties, Voters,
and the Risk Environment, A Mathematical Treatment of Electoral Competition Under
Uncertainty," in Richard G. Neimi and Herbert Weisberg (eds.) *Probability Models
of Collective Decision-Making* (Columbus: Charles E. Merrill, 1972); and Kenneth
A. Shepsle, "The Strategy of Ambiguity: Uncertainty and Electoral Competition,"
American Political Science Review, 66 (1972), 2:555-568.

call the "levels" of deterrence.[12] Their analysis discusses three levels of deterrence: strategic war, limited war, and potential crises. They note that a major problem in the development of efficacious deterrence policies has been assessing the appropriateness of a given policy for a given level. Such a discussion is relevant to the problems considered in the present research, and these distinctions are employed in the subsequent analysis, following the inclusion of the concepts of risk and uncertainty from statistical decision theory. After making this integration, other important relationships which have been only implicitly recognized by deterrence theorists between the levels, emerge.

Fourth, there has been a relative neglect of the dynamics of deterrence situations, as noted, including variations over time in decision makers' evaluations of outcomes, estimates and how these variations affect deterrence situations. This neglect is, of course, not entirely due to any lack of effort by deterrence theorists, although they should perhaps be faulted for lack of logical completeness in formulation of the statics of deterrence, but rather to the complexity of the abstract logic involved, a complexity suggested in subsequent sections of the present report.

Finally, there remains the problem of the empirical applicability of formal deterrence theory. Again, deterrence theorists cannot be criticized for a lack of due diligence on their part, and the difficulties of such applications are not surprising, given the relative complexity and abstractness of the mathematics involved. As considered in a later section, however, it is not entirely clear that these difficulties are insurmountable.

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[12]See George and Smoke, *Deterrence in American Foreign Policy*, pp. 38-57, for an extended discussion of these distinctions.

II. THE CLASSICAL MODEL OF DETERRENCE

Recognizing that all theoretical models employ assumptions that to varying degrees represent oversimplifications of reality, it is possible to formulate such a model in a highly abstract setting. Such a static model is set forth in the present chapter, with the caveat that the reader suspend any criticism or disbelief until the model is fully developed and articulated in subsequent chapters, with an application to general deterrence and crisis analysis.

2.1   Some Basic Assumptions

The fundamental analytical assumption is that a single decision maker is choosing and is a rational individual. This assumption implies that the decision maker is cognizant of the possible outcomes of a social situation; that he can rank these outcomes from most to least preferred; that his utility function can be constructed on this ordering; that he is aware of the possible courses of action open to him; that he can estimate the probability of a given outcome upon selection of an action; and that he chooses the action which, *ceteris paribus*, gives him the highest expected utility.[1]

Specifically, we assume that any decision maker has a *preference ordering* or *ranking* over the set $0 = \{0_1, 0_2, \ldots, 0_m\}$ of possible outcomes. That is, for any $0_i, 0_j, 0_k \in 0$:

1. $0_i \ R \ 0_j \lor 0_j \ R \ 0_i$ (Completeness)

2. $0_i \ R \ 0_i$ for all 0_i (Reflexivity)

3. $0_i \ R \ 0_j \land 0_j \ R \ 0_k \rightarrow 0_i \ R \ 0_k$ (Transitivity)

where $0_i \ R \ 0_j$ means 0_i is considered to be at least as good as 0_j. If $0_i \ R \ 0_j$ but $\neg 0_j \ R \ 0_i$ then we say that 0_i is preferred to 0_j, written $0_i \ P \ 0_j$.

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[1]See Kenneth J. Arrow, *Social Choice and Individual Values* (2nd ed.) (New Haven: Yale University Press, 1963), and John Von Neumann and Oskar Morgenstern, *The Theory of Games and Economic Behavior* (2nd ed.) (New York: John Wiley & Sons, 1954).

If O_i R O_j $\wedge$ O_j R O_i then we say that the decision maker is indifferent between O_i and O_j, written O_i I O_j.

If for each outcome there is an action that leads to it with *certainty* then the decision problem is simple. That is, if there is a set of actions, $A = \{A_1, A_2, ..., A_m\}$ such that

$$f(A_i) \rightarrow O_i$$

then the decision maker need simply select that action associated with his most preferred outcome.

Usually, however, any particular action may result in one of several outcomes. This necessitates the introduction of probabilities into the individual's decision calculus. A probability number is any number between 0 and 1 inclusive which expresses the likelihood of an event occurring. 0 represents an absolute certainty that an event will not occur while 1 represents an absolute certainty that an event will occur. Thus, in the case of decision making under certainty:

$$[PR(A_i) \rightarrow O_i] = 1, \quad [PR(A_i) = O_j \text{ for all } j \neq i] = 0$$

Decision making under *risk* involves situations where the probability that an action leads to a specific outcome is less than 1. Thus, we can represent the decision problem by the following matrix:

OUTCOMES

		O_1	O_2	O_3	. . . . .	O_m
	A_1	PR_{11}	PR_{12}	PR_{13}	. . . . .	PR_{1m}
	A_2	PR_{21}	PR_{22}	PR_{23}	. . . . .	PR_{2m}
ACTIONS	A_3	PR_{31}	PR_{32}	PR_{33}	. . . . .	PR_{3m}
	.	.	.	.		.
	.	.	.	.		.
	.	.	.	.		.
	A_n	PR_{n1}	PR_{n2}	PR_{n3}	. . . . .	PR_{nm}

where PR_{ij} is an abbreviation for $PR(O_j|A_i)$, the probability that action i results in outcome j. Since any action must lead to some outcome:

$$\sum_{j=1}^{m} PR_{ij} = 1 \text{ for all i.}$$

Given this state of uncertainty, how shall a decision maker choose between alternative courses of action? The Expected Utility (EU) decision rule says to weight (multiply) the utility of each outcome by its probability of occurrence and choose that action with the greatest sum of weighted utilities.[2] The utility of any outcome is simply an expression of the strength of satisfaction derived from that outcome.

Before the EU decision rule can be applied, the decision maker's utility function for the outcomes must be constructed or discovered. In some cases we may assume that there exists a specific functional relationship between the quantity of a commodity possessed by an individual and the individual's utility. For example, Daniel Bernoulli suggested that the relationship between money and a person's subjective value (utility) of that money is not linear but exponential. The basic idea is that utility of one additional dollar is less for a millionaire than for a pauper. This kind of relationship is shown in Figure 2.1 where the function

$$U = 1 - e^{bV}$$

is plotted. The constant b is negative for this plot, U stands for utility and V for objective value.[3]

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[2] There are other decision rules than EU--specifically, those which make no use of probability estimates: the minimax, minimax-regret, Laplace and optimism-pessimism decision rules. However, for various reasons the EU rule seems a more realistic description of actual decision makers' calculations. For example, given reasonable assumptions concerning the preference ordering of a potential aggressor over possible action-response sequences, the minimax and minimax-regret rules (regardless of utilities and probabilities) *always* call for an attack. For a description of all four rules see J. Milnor, "Games Against Nature," pp. 49-59 in R. M. Thrall, C. H. Coombs, and R. L. Davis (eds.), *Decision Processes* (New York: John Wiley 1954).

[3] See Lawrence D. Phillips, *Bayesian Statistics for Social Scientists* (New York: Thomas Y. Crowell 1973), p. 102.
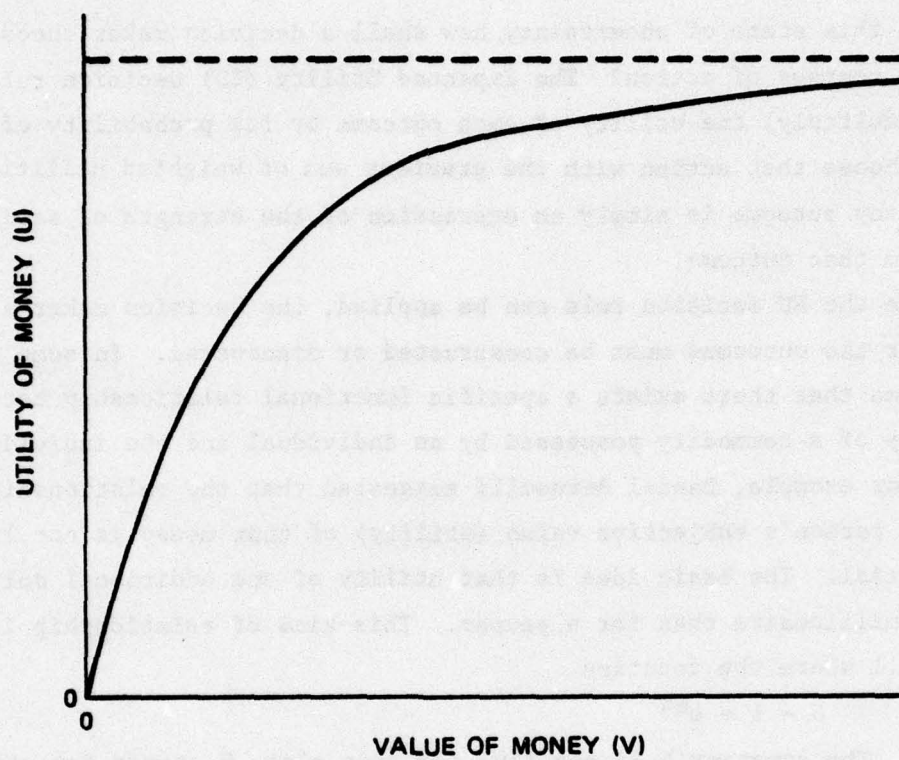
Figure 2.1 Utility of Money

The y-axis is labeled "UTILITY OF MONEY (U)" and the x-axis is labeled "VALUE OF MONEY (V)".

In other instances, values may be assigned to the most preferred and least preferred outcomes for the decision maker, and determined for any outcome ranked in between the value of $PR(O_1)$ which will make the decision maker indifferent between receiving that specific middle ranked outcome for certain and the lottery $[PR(O_1), O_1; 1-PR(O_1), O_m]$, where, in this case, $PR(O_1)$ is the decision maker's probability of receiving his most preferred outcome and $PR(O_m)$ the probability of receiving the least preferred. Using the standard $[0,1]$ normalization, under which $U(O_1) = 1$ and $U(O_m) = 0$, the utility for the middle ranked outcome will simply be that value of $PR(O_1)$ which makes the decision maker indifferent between that outcome for certain and the gamble between his most and least preferred outcomes.[4]

Note that the decision maker's utility function and the resulting EU calculations are a direct function of his preference ordering and an infinite series of real numbers is available for assignment to the outcomes. However, these difficulties are partially resolved by observing that there are only thirteen distinct orderings of three outcomes, as shown in Table 2.1.

To illustrate, the EU calculations assume that $A = \{A_1, A_2\}$ and that A_1 yields the decision maker O_2 with certainty: that is, $PR(O_2/A_1) = 1$ and that A_2 yields O_1 with estimated probability $PR(O_1/A_2)$ and O_3 with estimated probability $PR(O_3/A_2)$ where $PR(O_1/A_1) + PR(O_3/A_2) = 1$, then $PR(O_2/A_2) = 0$. Thus,

$$EU(A_1) = PR(O_1/A_1) \times U(O_1) + PR(O_2/A_1) \times U(O_2) + PR(O_3/A_1) \times U(O_3)$$

$$= PR(O_2/A_1) \times U(O_2)$$

$$= U(O_2)$$

---

[4] See John Von Neumann and Oskar Morgenstern, *The Theory of Games and Economic Behavior*; Peter Fishburn, "Utility Theory," *Management Science*, 14 (1968); John Chipman, "The Foundations of Utility," *Econometrica*, 18 (1950); R. Duncan Luce and Howard Raiffa, *Games and Decisions* (New York: John Wiley & Sons, 1957); and I. J. Good, "The Appropriate Mathematical Tools for Describing and Measuring Uncertainty," in C. F. Carter, G. P. Meredith and G. L. S. Shackle (eds.), *Uncertainty and Business Decisions* (Liverpool: University Press of Liverpool, 1954).

TABLE 2.1

POSSIBLE PREFERENCE ORDERINGS OVER OUTCOMES

Preference Ordering	Relation Between Outcomes				
I	O_1	P	O_2	P	O_3
II	O_1	P	O_2	I	O_3
III	O_1	I	O_2	P	O_3
IV	O_1	P	O_3	P	O_2
V	O_1	I	O_3	P	O_2
VI	O_3	P	O_1	P	O_2
VII	O_3	P	O_2	I	O_1
VIII	O_3	P	O_2	P	O_1
IX	O_3	I	O_2	P	O_1
X	O_2	P	O_3	P	O_1
XI	O_2	P	O_1	I	O_3
XII	O_2	P	O_1	P	O_3
XIII	O_1	I	O_2	I	O_3

$$EU\,(A_2) \;=\; PR(O_1/A_2) \;\times\; U(O\text{ }) \;+\; PR(O_2/A_2) \;\times\; U(O_2) \;+\; PR(O_3/A_2) \;\times\; U(O_3)$$

$$=\; PR(O_1/A_2) \;\times\; U(O_1) \;+\; PR(O_3/A_2) \;\times\; U(O_3)$$

He then chooses that action which yields the larger EU: e.g., if $EU(A_1)$ $> EU(A_2)$, he chooses A_1.

Now, suppose the decision maker has selected I as his preference ordering; then, substituting from Table 2.2,

$$EU(A_1) \;=\; U(O_2)$$

$$=\; k_2$$

and

$$EU(A_2) \;=\; PR(O_1/A_2) \;\times\; U(O_1) \;+\; PR(O_3/A_2) \;\times\; U(O_3)$$

$$=\; PR(O_1 A_2) \;\times\; 1 \;+\; PR(O_3/A_2) \;\times\; 0$$

$$=\; PR(O_1/A_2).$$

Thus, he selects A_1 if and only if k_2, the normalized utility of O_2, is greater than $PR(O_1/A_2)$; he selects A_2 if this relationship is reversed; and, if the EU's are equal, he is indifferent between A_1 and A_2.

By contrast, suppose the decision maker selects II as his ordering; then

$$EU(A_1) \;=\; 0$$

and

$$EU(A_2) \;=\; PR(O_1/A_2).$$

Since $PR(O_1/A_2) > 0$, he selects A_2. Suppose he selects ordering III; then $EU(A_1) = 1$, $EU(A_2) = PR(O_1/A_2)$ and, since $PR(O_1/A_2) < 1$, he selects A_1.

2.2 Defining Deterrence

The first theoretical *and* empirical difficulty that is encountered in any study of inter-nation deterrence is definition of the term itself. While not absolutely crucial to our analysis, such a definition is useful for focusing attention on key factors, especially in empirical work. A useful

TABLE 2.2

UTILITY ASSIGNMENTS FOR POSSIBLE OUTCOMES

Preference Ordering	$U(O_1)$	$U(O_2)$	$U(O_3)$
I	1	k_2	0
II	1	0	0
III	1	1	0
IV	1	0	k_3
V	1	0	1
VI	k_1^a	0	1
VII	0	0	1
VIII	0	k_2	1
IX	0	1	1
X	0	1	k_3
XI	0	1	0
XII	k_1	1	0
XIII	1	1	1

^{a}for all k_1, $0 < k_1 < 1$

distinction has been made by Morgan, who conceives of two types of deterrence:[5]

> Immediate Deterrence concerns the relationship between opposing states where at least one side is seriously considering an attack (or threat) while the other is mounting a threat of (some type of) retaliation in order to prevent it.

> General Deterrence relates to opponents who maintain armed forces to regulate their relationship even though neither is anywhere near mounting an attack (or threat).

Having noted that deterrence is rooted in decision making, it is possible to turn to specifying the conditions under which an immediate or pure deterrence situation exists. They appear to be as follows:

(1) In a relationship between two hostile states, the officials in at least one of them are seriously considering attacking (or threatening) the other or attacking (or threatening) some area of the world the other deems important (or potentially important);

(2) Key officials of the state that is to be the target of the attack (or threat) must realize this;

(3) The target state, realizing that an attack (or threat) is a distinct possibility, must threaten the use of force in retaliation in an attempt to prevent attack (or threat);

(4) Leaders of the state planning to attack (or threaten) must decide to desist primarily because of the retaliatory threat(s) of the opponent.

The following are the characteristics of a general deterrence situation:

(1) Relations between opponents are such that leaders in at least one would consider resorting to force if the opportunity (or, in the views of the leaders, necessity) arose;

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[5] Patrick M. Morgan, *Deterrence: A Conceptual Analysis* (Beverly Hills: Sage Publications, 1977). Additions to Morgan's statement are enclosed in parentheses.

(2)   The other side, precisely because it believes the
       opponent would be willing to consider resort to
       force, maintains forces of its own and offers
       warnings to respond in kind to attempts to use
       force contrary to its interests;

(3)   The decision makers at whom the general deterrent
       threat is aimed do not go beyond preliminary
       consideration of resorting to force (or threats)
       because of the expectation that such a policy
       would result in a corresponding resort to
       force of some sort by leaders of the opposing
       state.

Morgan's distinctions are made more relevant to the present work by
adapting some additional distinctions made by George and Smoke.[6] They
note that implicitly there are at least three "levels of deterrence"
which decision makers must face in real world deterrence situations,
distinguished roughly by the magnitude of the immediate destruction that
may arise if deterrence fails: (1) strategic war, e.g., a war between the
United States and the Soviet Union; (2) limited war, e.g., Korea or Vietnam;
and (3) potential crises, e.g., areas of the world, like the Middle East or
southern Africa, where originally localized conflicts have drawn or may draw
in the United States, U.S.S.R. or other world powers. Combining George
and Smoke's levels with Morgan's distinction, we obtain a rough, six-
fold classification, which is more explicitly developed subsequently, of
deterrence situations. This typology is displayed in Table 2.3.

A second term that involves definitional difficulties is the term
crisis itself. Scholars have employed a variety of definitions and conceptu-
alizations in their analyses of crisis situations.[7] Most useful for purposes
of the present research is the three part definition of Michael Nicholson[8]:

_____

[6]*Deterrence in American Foreign Policy*, pp. 38-57.

[7]For a summary and discussion of a number of approaches to crisis analysis,
see J. Dedring, *Recent Advances in Peace and Conflict Research: A Critical
Survey* (Beverly Hills: Sage Publications, 1976).

[8]Michael Nicholson, "Uncertainty and Crisis Behavior: An Illustration of
Conflict and Peace Research," in C. F. Carter and J. Ford (eds.), *Uncertainty
and Expectations in Economics* (Oxford, England: Blackwell's, 1972).

TABLE 2.3

TYPOLOGY OF POSSIBLE DETERRENCE SITUATIONS

LEVELS OF CONFLICT	EXAMPLES[a]	
	GENERAL DETERRENCE	IMMEDIATE DETERRENCE
Strategic or Nuclear War	Relations between U.S. and U.S.S.R.	Cuban Missile Crisis
Limited War	Middle East	Two Week Period Prior to 1967 Six Day War
Potential Crises	Southern Africa	Berlin

[a] These examples are intended as suggestive, not definitive.

A crisis can be defined by three characteristics. First, it is a period of great uncertainty, where the gap between the best outcome and the worst outcome of the situation is very large in comparison with normal. In the sort of situation we are considering the worst outcome is war (or at least defeat in war) while the best outcome is the status quo which in probability language can be described as the situation where the probability of an adverse outcome is high compared with normal. . . The second characteristic is that the crisis takes place over a short period of time (which justifies the use of the word 'abnormal' to describe it). The third characteristic is that the problems which occasion the crisis are unexpected to at least one of the parties involved.

Thus, in a crisis situation, the parties involved are trying to avoid the outbreak of hostilities while trying to achieve some national objective. At the same time they are fearful of being the victim of a preemptive attack by their enemy. Hence, the examples given under the "Immediate Deterrence" column of Table 2.3 are all crisis situations. The classical model of deterrence which follows applies mainly to General Deterrence situations, especially those involving strategic nuclear or limited war. The model developed in Chapter III, below, applies to various crisis situations that fall in the Immediate Deterrence category.

2.3   The Calculus of Deterrence

Following the lead of previous deterrence theorists, and paralleling the model outlined in section 2.1, we first present some fundamental assumptions.[9]

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[9]Some earlier theorists of importance are Bernard Brodie, *Strategy in the Missile Age* (Princeton: Princeton University Press, 1959); Charles F. Doran, "A Theory of Bounded Deterrence," *Journal of Conflict Resolution*, 17 (1973); Daniel Ellsberg, "The Crude Analysis of Strategic Choices," (P-2183)(Santa Monica: The Rand Corporation, 1969); Clifton F. Fink, "More Calculations About Deterrence," *Journal of Conflict Resolution*, 9 (1965); Douglas E. Hunter, "Aspects of a Decision Making Model of Deterrence," *Journal of Peace Research*, 9 (1972); Herman Kahn, *On Escalation: Metaphors and Scenarios* (New York: Praeger, 1965); T. W. Milburn, "What Constitutes Effective Deterrence," *Journal of Conflict Resolution*, 3 (1959); Bruce M. Russett, "The Calculus of Deterrence," *Journal of Conflict Resolution*, 7 (1963); Thomas C. Schelling, *Arms and Influence*, (New Haven: Yale University Press, 1966); Thomas C. Schelling, *The Strategy of Conflict* (Cambridge: Harvard University Press, 1960); and Glenn H. Snyder, *Deterrence and Defense: Toward a Theory of National Security* (Princeton: Princeton University Press, 1960). Earlier comments regarding the nature of the assumptions apply here as well. The empirical difficulties that these assumptions engender are discussed in subsequent sections.

It can be assumed that in the deterrence situation there are only two prin-
cipal actors, although sub-actors such as "client states" are allowed and
are labeled either deterer and deteree or defender and aggressor. Initi-
ally, however, the deterrence situation is considered only from a potential
aggressor's point of view. While recognizing that deterrence situations
are fundamentally interdependent decision situations, we temporarily post-
pone consideration of possible defender responses to an aggressor's
actions and the aggressor's estimates of the likelihood of these possible
responses.[10] Thus, the deterrence decision problem can be simplified by
focusing on the process through which a potential aggressor decides to
adopt, or not adopt, a particular course of action.

Paralleling Section 2.1, it is assumed that a potential aggressor is
a rational decision maker. As noted, this implies that he can rank the
possible outcomes in a deterrence situation; that his utility function can
be constructed on his preference ordering over outcomes; that he is suf-
ficiently intelligent to estimate the probabilities of various outcomes,
contingent upon selection of a course of action, with these probability
estimates being either specific real numbers or some range of numbers
between 0 and 1 inclusive; that he can relate (through his probability
estimates) his possible courses of action to the possible outcomes in such
a way as to establish his preference ordering for actions and that, in
establishing his preferences for actions, an actual selection of one
course of action to follow, he chooses that action which, *ceteris paribus*,
yields him the highest expected utility.[11]

To illustrate the traditional deterrence calculus, the analysis focuses
on the strategic war level of deterrence. While recognizing that a modern
strategic war would likely be fought with nuclear weapons, it is useful to
define strategic war as an attack with conventional and/or nuclear forces on
one principal actor's homeland by the other. Note that such an attack may or
may not entail significant retaliation on the attacker, depending upon the

[10] For one discussion of these factors, see Mueller, *Deterrence, Numbers and History*, pp. 15-16.

[11] For a critique of this view and alternative models, see Graham T. Allison, *Essence of Decision: Explaining the Cuban Missile Crisis* (Boston: Little, Brown & Co., 1971).

degree of success of the attacker's first strike or attack.

In the simplest strategic war deterrence situation, there are three possible outcomes:

(1) <u>Victory</u>, V, defined as a completely successful first strike or attack such that the victim cannot retaliate on the attacker;

(2) <u>Defeat</u>, D, defined as an unsuccessful first strike or attack such that the victim is able to retaliate on the attacker, and damage may range from minimal or acceptable (in the mind of the attacker) to total devastation; and

(3) <u>Status Quo</u>, SQ, which is the outcome that obtains if a potential aggressor chooses not to initiate a strategic war.

To determine the course of action that a potential aggressor selects, we must first discover his preference ordering for the three outcomes. In general and as discussed subsequently, the construction of his preference ordering requires a potential aggressor to weigh the benefits versus the costs of each outcome. For example, a potential benefit of V would be worldwide economic, military and political hegemony. Costs, both real and opportunity, however, would be incurred in the expenditures of scarce resources required to build and replace sufficient conventional and nuclear forces to obtain V and then maintain world hegemony after destruction of the other principal actor.

Nevertheless, we assume that a potential aggressor, in his own mind, can weigh the benefits versus costs of each outcome and arrive at a preference ordering for the outcomes.[12] Thus, recalling Table 2.1, we see that there are thirteen possible orderings of three outcomes and V corresponds to 0_1; SQ to 0_2; and D to 0_3. We assume that upon completion of his benefit-cost calculations, a potential aggressor can select one of these orderings as his own. Regarding a potential aggressor's utility function for outcomes, we

_____

[12]At this point, the factors entering an actor's benefit-cost calculations are not specified because these are more appropriately assessed in a subsequent discussion of empirical applications.

note a similar correspondence between V, SQ, and D and O_1, O_2, and O_3 in Table 2.2.

In this deterrence situation, there are two possible courses of action open to a potential aggressor:

(1)   not to initiate strategic war, labeled A_1; and

(2)   to initiate strategic war, labeled A_2.

As in section 2.1, if the decision maker selects A_1, he obtains the certain outcome SQ, and his "payoff" is U(SQ); that is, $EU(A_1) = U(SQ)$. If he selects A_2, the situation is more problematic. Recalling the definition of V, it is possible to note that a significant element of uncertainty is present as a potential aggressor may not, prior to the selection of A_2, know what the "true" possibility of obtaining V, $PR(V/A_2)$, corresponding to $PR(O_1/A_2)$, actually is.

Even though based on the information available to him, his estimate will nevertheless contain both subjective and objective elements, and it can reasonably be expected that $PR(V/A_2) < 1$, though his estimate may be quite large. Thus, as in Section 2.1, selection of A_2 entails a lottery in which a potential aggressor has some probability $PR(V/A_2)$, which initially we assume he estimates as a specific real number, of obtaining V and some probability $PR(D/A_2) = 1 - PR(V/A_2)$ of realizing D.

The question the potential aggressor must ask himself is: Is the expected utility of attack greater than that of not attacking, or the status quo? That is, is

$$PR(V/A_2) \times U(V) + PR(D/A_2) \times U(D) > U(SQ)$$

If so, then the optimal action is to attack.[13] To illustrate, suppose a potential aggressor has selected preference ordering I as his own, then

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[13]A more complicated situation arises when the deterrer has a set of possible responses $R = \{R_1, R_2, \ldots, R_\ell\}$ to any potential aggression, some of which are adequate to defeat an aggressor, others of which are not. With each response will be associated a particular probability of victory and utility of victory (since the costs involved in achieving victory will vary), and a particular probability of defeat and disutility of defeat. Letting,

$$EU(A_1) = U(SQ) = k_2$$

and

$$EU(A_2) = PR(V/A_2) \times U(V) + PR(D/A_2) \times U(D)$$

$$= PR(V/A_2) \times 1 + PR(D/A_2) \times 0$$

$$= PR(V/A_2).$$

A potential aggressor is deterred, that is, selects A_1 if, and only if, $EU(A_1) > EU(A_2)$. Deterrence fails; he selects A_2 if, and only if, $EU(A_1) < EU(A_2)$. If $EU(A_1) = EU(A_2)$, deterrence may succeed or fail, depending upon factors other than those in the immediate calculation: e.g., manipulation by a defender of $PR(V/A_2)$ and/or the benefit-cost calculations of a potential aggressor.

Re-examining the condition for successful deterrence, $EU(A_1) > EU(A_2)$, we have $k_2 > PR(V/A_2)$. In other words, deterrence succeeds if, and only if, the normalized utility of SQ is greater than $PR(V/A_2)$. In this context, the age old problem regarding deterrence (namely, we usually know when deterrence fails, but we often do not know when, or why, it succeeds) is relevant. Specifically, more than one preference ordering is consistent with $k_2 >$

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13 (cont'd)

$\quad PR(V/A_1/R_j)$ be the probability of victory given an attack,
$\qquad\qquad\qquad$ action A_2, and response R_j,
$\quad U(V/R_j) \qquad$ be the utility of victory given response R_j, and
$PR(D/A_2/R_j)$ and $U(D/R_j)$ be similarly defined, then the potential aggressor
will attack if and only if

$$\sum_{j=1}^{\ell} (PR(V/A_2/R_j) \times U(V/R_j) + PR(D/A_2/R_j) \times U(D/R_j)) > U(SQ)$$

$PR(V/A_2)$.[14] Table 2.4 indicates for which orderings deterrence always succeeds, fails, or is indeterminate. Examine Table 2.4: in five cases (III, IX, X, XI and XII) a potential aggressor is always deterred regardless of his estimate of $PR(V/A_2)$; in five cases (II, IV, V, VI, and VII) deterrence never succeeds; and in three cases (I, VIII and XIII) is indeterminable, that is, depends on a potential aggressor's U(SQ) and his estimate of $PR(V/A_2)$.[15]

In sum, deterrence of a potential aggressor depends on three fundamental factors: (1) his preference ordering for the possible outcomes of the deterrence situation; (2) if, and only if, SQ is his Middle Ranked Outcome (MRO), the relative valuation of SQ compared to V and D: that is, assuming preference ordering I, the relative magnitude of U(V) - U(SQ) versus U(SQ) - U(D); and (3) his estimate of $PR(V/A_2)$. Similarly, a defender, in his efforts to influence a potential aggressor's selection of A_1 or A_2, must address four basic questions: (1) What is the potential aggressor's preference ordering for the possible outcomes of the deterrence situation? (2) How can that ordering be influenced? (3) If SQ is the potential aggressor's MRO, how can his evaluation of it versus V and D be influenced? (4) How can his estimate of $PR(V/A_2)$ be influenced? (5) How does dealing with one question affect answers to the others: that is, how are the factors relevant to the potential aggressor's decision interrelated?

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[14] This point is made by Fink, "More Calculations About Deterrence,"; John E. Mueller (ed.), *Approaches to Measurement in International Relations* (New York: Appleton-Century-Crofts, 1969); and John E. Mueller, *Deterrence, Numbers and History* (Los Angeles: University of California Security Studies Project, 1968).

[15] Orderings V, VI, VII, VIII, IX and XIII are, empirically, rather perverse. Writing in a similar vein, Mueller, *Approaches to Measurement in International Relations*, pp. 284-285, notes: "Suppose. . .that the attacker is a masochist who prefers defeat to victory. . .Then to deter, one wishes to make the probability of victory as *high* as possible."

TABLE 2.4

PREFERENCE ORDERINGS AND SUCCESSFUL DETERRENCE

Preference Ordering	$U(V)$	$U(SQ)$	$U(D)$	$k_2 > PR(V\|A_2)$?
I	1	k_2	0	uncertain
II	1	0	0	never
III	1	1	0	always
IV	1	0	k_3	never
V	1	0	1	never
VI	k_1	0	1	never
VII	0	0	1	never
VIII	0	k_2	1	uncertain
IX	0	1	1	always
X	0	1	k_3	always
XI	0	1	0	always
XII	k_1	1	0	always
XIII	1	1	1	uncertain

2.4 Risk and Uncertainty

Risk and the attitudes of national decision makers toward it are in many cases vitally important to their ultimate policy decisions. In this context, there are a number of key questions to be considered. First, is the decision maker by nature, before he is called upon to decide between A_1 and A_2, a gambler or not? That is, is he disposed to accept risks (risk acceptant, RAC), avoid them (risk averse, RAV), or equally disposed (risk neutral, RNE) toward the various risks that may inhere in decision situations? Second, does the decision maker, regardless of whether or not he is risk acceptant, risk averse or risk neutral, make specific probability estimates of the possible outcomes of his actions, or does he estimate some range of numbers between 0 and 1 in which he believes the "true" probability to fall?

To illustrate how these constructs apply as well as their relevance, suppose the decision maker has selected preference ordering I and is contemplating his EU for each action. If he selects A_1, $EU(A_1) = k_2$. However, if he selects A_2, he is actually selecting a lottery between 0_1 and 0_3. Here, the key elements in his evaluation of A_2 are his estimates of $PR(0_1/A_2)$ and $PR(0_3/A_2)$, and the EU that these estimates generate. In other words, he must evaluate the lottery $(PR(0_1/A_2), 0_1; PR(0_3/A_2), 0_3)$.

We note that as $PR(0_1/A_2)$ varies from 0 to 1, a series of lotteries is generated which varies from $(0, 0_1; 1, 0_3)$ to $(1, 0_1; 0, 0_3)$ and, by assumption of ordering I, the latter is his most preferred lottery and the former his least preferred. Thus, it is possible to construct the decision maker's utility function for all lotteries involving 0_1 and 0_2, and $U(0, 0_1; 1, 0_3) = 0$ and $U(1, 0_1; 0, 0_3) = 1$. Since 0_2, his middle ranked outcome, has $U(0_2) = k_2$, $0 < k_2 < 1$, we know it is equivalent to the utility of some lottery between $(0, 0_1; 1, 0_3)$ and $(1, 0_1; 0, 0_3)$: that is, for some $PR(0_1/A_2)$ and $PR(0_3/A_2)$, say $PR(0_1/A_2)*$ and $PR(0_3/A_2)*$, $U(0_2) = U(PR(0_1/A_2)*, 0_1; PR(0_3/A_2)*, 0_3)$.

As mentioned, the first key question is: Is the decision maker risk averse or not? The terms are RAV for the non-gambler, RNE for the indif-

ferent (as explained below), and RAC for the gambler. Each of these personality types is distinguished by the shape of his utility functions on lotteries between O_1 and O_3. In this context, there are three general shapes. A RAV decision maker has a concave utility function defined on all lotteries ranging from $(0,O_1;1,O_3)$ to $(1,O_1;0,O_3)$; a RNE decision maker has a linear utility function; and a RAC decision maker a convex utility function. These three fundamental types are illustrated in Figure 2.2.

The significance of the distinction between RAV, RNE, and RAC decision makers resides in the fact that, faced with the identical decision situation, each makes a different choice. To illustrate, suppose, for the moment, that three decision makers exist all with ordering I, and each makes the same probability estimates, $PR(O_1/A_2) = PR(O_3/A_2) = 1/2$ but one decision maker is RAV, another RNE, and the third RAC. Further, suppose that, for all three, it is determined that $U(O_2) = (1/2, O_1; 1/2, O_3)$. Recall the application of the EU decision rule to evaluation of A_2. In Figure 2.2, the EU of each lottery resulting from the decision maker's selection of A_2 varies as the lottery varies from $[(0,O_1;1,O_3)]$ to $[(1,O_1;0,O_3)]$.

Examining Figure 2.3 it is possible to note that for the RAV decision maker:

$$EU(A_1) = U_{RAV}(O_2) > EU(A_2) = EU(1/2, O_1; 1/2, O_3)$$

$$= 1/2 \times U(O_1) + 1/2 \times U(O_3)$$

$$= 1/2;$$

for the RNE decision maker:

$$EU(A_1) = U_{RNE}(O_2) = EU(A_2) = EU(1/2, O_1; 1/2, O_3)$$

$$= 1/2;$$

and for the RAC decision maker:

$$EU(A_1) = U_{RAC}(O_2) < EU(A_2) = EU(1/2, O_1; 1/2, O_3)$$

$$= 1/2.$$
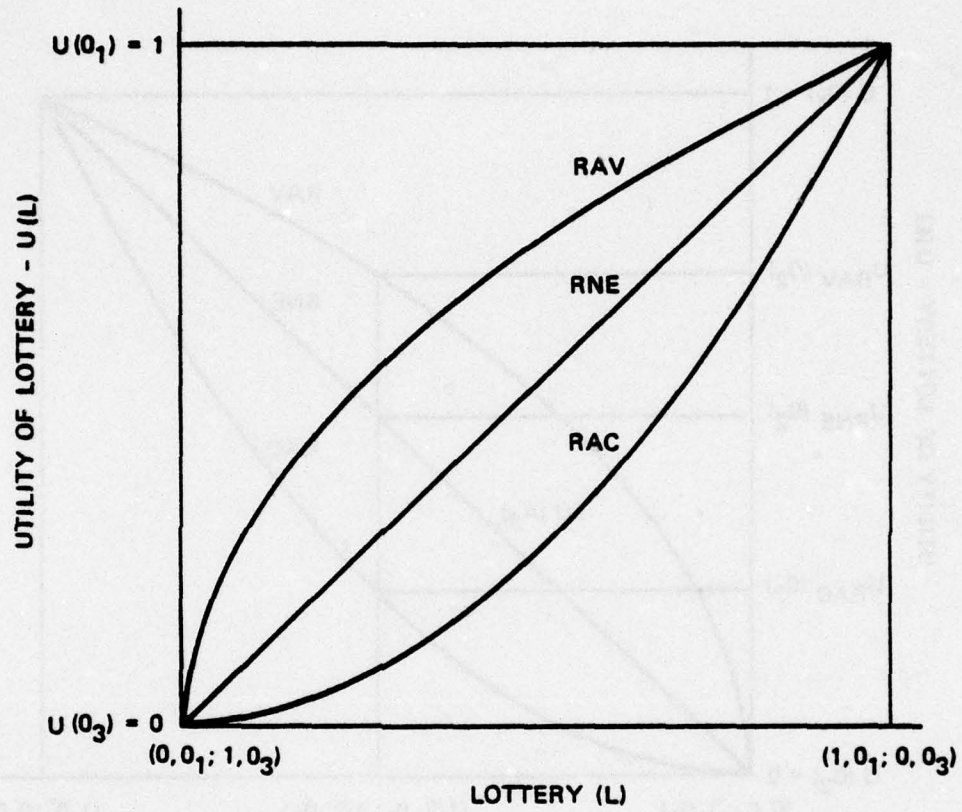
Figure 2.2 Alternative Utility Functions
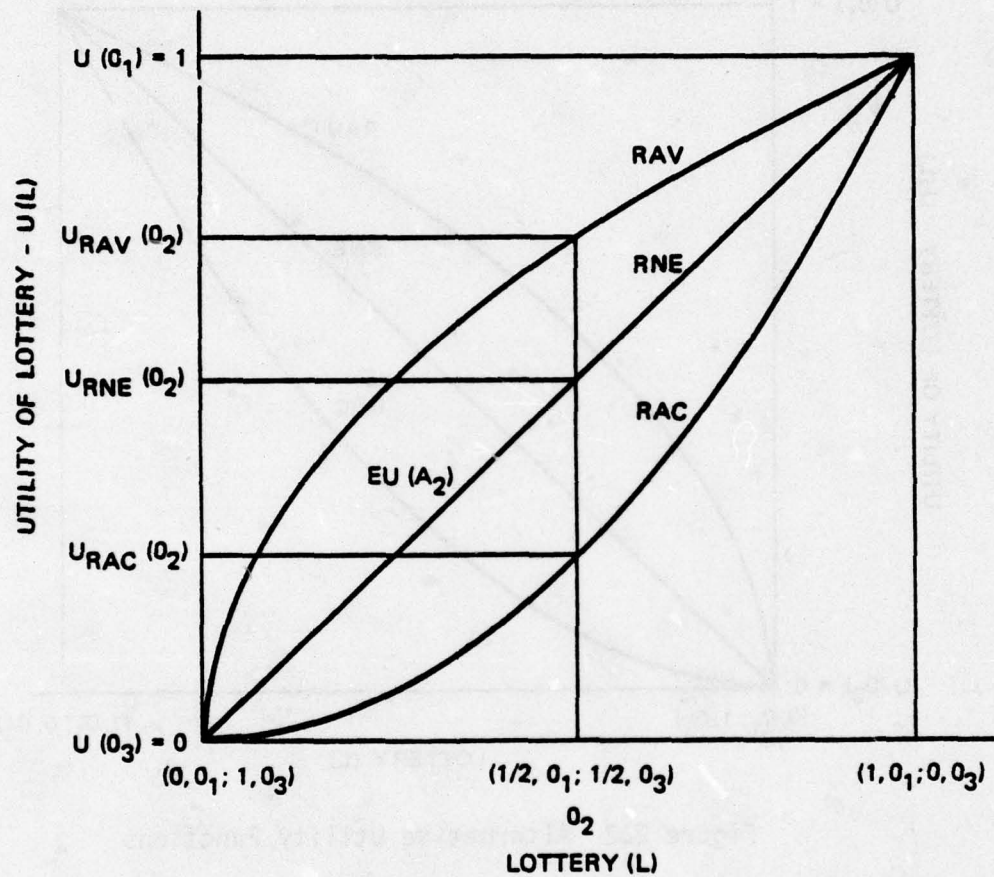
Figure 2.3 Outcome O_2 Utilities

Thus, *ceteris paribus*, the RAV decision maker chooses A_1; the RNE decision maker is indifferent between A_1 and A_2; and the RAC decision maker chooses A_2.

An alternative way of stating the import of the result is that the RAV decision maker prefers the "certain" outcome 0_2 to the more "risky" lottery option $(1/2, 0_1; 1/2, 0_3)$: namely, he is "averse" to taking the risks inherent in lotteries; the RNE decision maker is indifferent between the certain outcome and the lottery option: that is, he is "neutral" when required to choose between a certain outcome and a lottery option; and the RAC decision maker prefers the lottery option to the certain outcome: that is, he is "acceptant" of the risks inherent in lotteries.

In fact, closer scrutiny of Figure 2.3 provides the technical definitions of each type of decision maker. We see that, owing to the shape of his utility function, the RAV decision maker always prefers certain options to lottery options as expected utility of the lottery (EU(L)) for all lotteries (L) is always less than the utility of the corresponding certain option. The RNE decision maker is always indifferent between certain and lottery options. The RAC decision maker always perfers lottery options as the expected utility of the lottery (EU(L)) for all lotteries (L) is always greater than the utility of the corresponding certain option.

The second key question is: Does the decision maker make specific estimates of $PR(0_1/A_2)$ and $PR(0_3/A_2)$, or does he estimate some range of numbers between 0 and 1 in which he believes the "true" probabilities to fall? Suppose, for example, that during his estimation process the decision maker observes to himself: "Based on the information I have about the consequences attendant upon selection of A_2, I don't think I can come up with specific estimates for $PR(0_1/A_2)$ and $PR(0_3/A_2)$." In other words, he cannot decide (he is *uncertain*) which specific lottery will result from selection of A_2. "However, it seems to me that $PR(0_1/A_2)$ falls between two particular numbers." In other words, he believes that the "true" values of $PR(0_1/A_2)$ and $PR(0_3/A_2)$ and the corresponding "true" lottery fall in some range, e.g., an interval [a;b], where a and b are specific values of $PR(0_1/A_2)$ and a < b.

"For lack of any better information, suppose every lottery in the interval [a;b] is equally likely to occur." Thus, the decision maker believes

that, if he selects A_2, all lotteries in the interval [a;b] are equally likely to obtain. This type of estimate is called a "risk function," R(L), and is a probability distribution, a "lottery on lotteries," defined over the set of lotteries in [a;b]. R(L) conforms to the mathematical condition required of all such distributions, namely

$$\int_a^b R(L)dL = 1.$$

These concepts are displayed graphically in Figure 2.4.

"Having estimated $PR(0_1/A_2)$ and $PR(0_3/A_2)$ this way, how can I choose between A_1 and A_2?" Note that this decision situation is rather different than earlier. Action A_1 still leads to $EU(A_2) = U(0_2) = k_2$. However, selection of A_2 leads, not to a specific lottery between 0_1 and 0_3, but a set of lotteries each of which occurs with some estimated probability as given by R(L); and the $EU(A_2)$ calculation is not straightforward. Although much more complex, the decision maker can still calculate this quantity and choose between A_1 and A_2.

In situations such as these, the EU of an action is obtained by multiplying the decision maker's estimated risk function by his utility function and integrating the product over the range to the risk function. Thus,

$$EU(A_2) = \int_a^b R(L)U(L)dL$$

since R(L) is assumed constant over any [a;b]. R(L) = 1/(b-a), and the calculation becomes

$$EU(A_2) = 1/(b-a) \int_a^b U(L)dL.$$

The significance of this differing approach to probability estimates lies in the fact that two decision makers, both of whom are RAV, RNE, or RAC and faced with the same situation, make different choices depending upon which type of probability estimates they make. Before considering this,

$U(O_1) = 1$

UTILITY OF LOTTERY - U(L)

RISK FUNCTION - R(L)

$U(O_3) = 0$

| $(0, O_1; 1, O_3)$ | a | $(1/2, O_1; 1/2, O_3)$ | b | $(1, O_1; 0, O_3)$ |

O_2
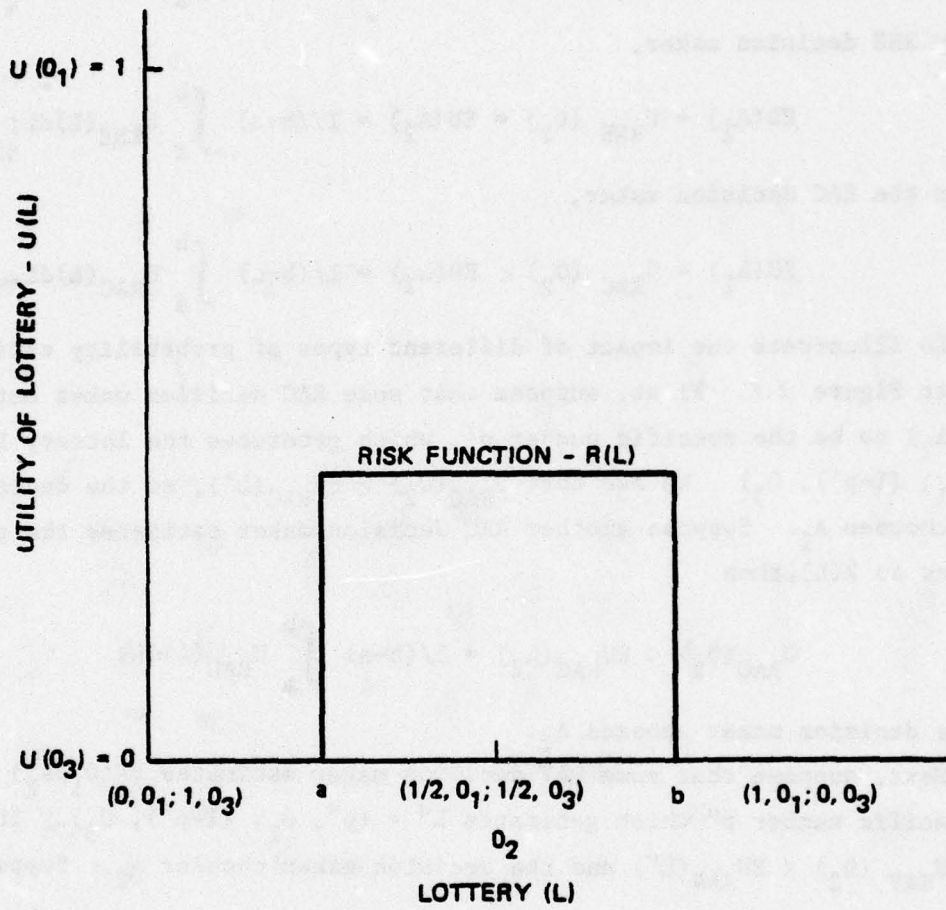
LOTTERY (L)

Figure 2.4   Risk Function on Lotteries

however, let us return for a moment to the preceding analysis. Examining Figure 2.5, which is Figure 2.4 superimposed on Figure 2.3, we note that O_2 is located at the midpoint of $[a;b]$.[16] Further adapting this approach, we find it is still the case that for the RAV decision maker,

$$EU(A_1) = U_{RAV}(O_2) > EU(A_2) = 1/(b-a) \int_a^b U_{RAV}(L)dL;$$

for the RNE decision maker,

$$EU(A_1) = U_{RNE}(O_2) = EU(A_2) = 1/(b-a) \int_a^b U_{RNE}(L)dL;$$

and for the RAC decision maker,

$$EU(A_1) = U_{RAC}(O_2) < EU(A_2) = 1/(b-a) \int_a^b U_{RAC}(L)dL.$$

To illustrate the impact of different types of probability estimates, consider Figure 2.6. First, suppose that some RAC decision maker estimates $PR(O_1/A_2)$ to be the specific number p', which generates the lottery $L' = (p', O_1; (1-p'), O_3)$. We see that $U_{RAC}(O_2) > EU_{RAC}(L')$, so the decision maker chooses A_1. Suppose another RAC decision maker estimates the probabilities as $R(L)$, then

$$U_{RAC}(O_2) < EU_{RAC}(A_2) = 1/(b-a) \int_a^b U_{RAC}(L)dL,$$

and the decision maker chooses A_2.

Next, suppose that some RAV decision maker estimates $PR(O_1/A_2)$ to be the specific number p'' which generates $L'' = (p'', O_1; (1-p''), O_3)$. In this case, $U_{RAV}(O_2) < EU_{RAV}(L'')$ and the decision maker chooses A_2. Suppose another

---

[16]Unfortunately, for these results to apply, these somewhat restrictive conditions must be met, namely, $R(L)$ constant and O_2 located at the midpoint of $[a;b]$. If these restrictions are dropped, it does not mean these conclusions no longer hold, but that the analysis entails a degree of complexity not yet explored and far beyond the scope of this report. However, as discussed subsequently, it is felt that even with these restrictions the model is sufficiently broad in scope to cover a wide range of empirical situations.
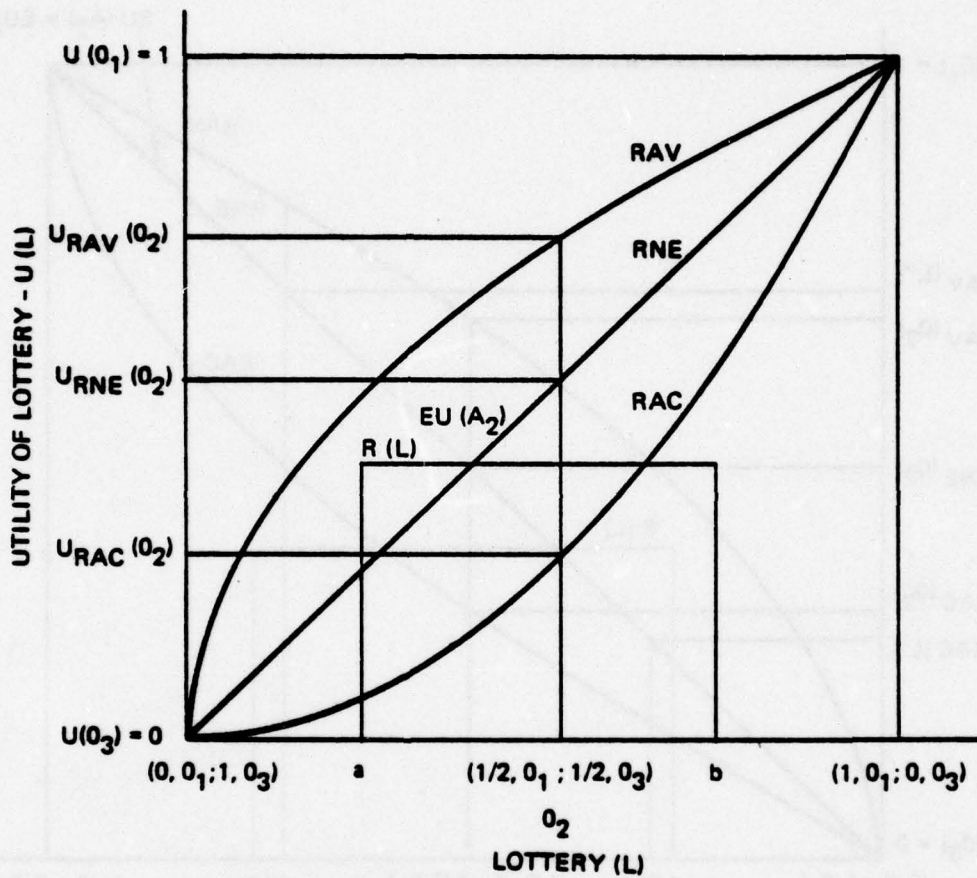
Figure 2.5 Risk and Utility Functions
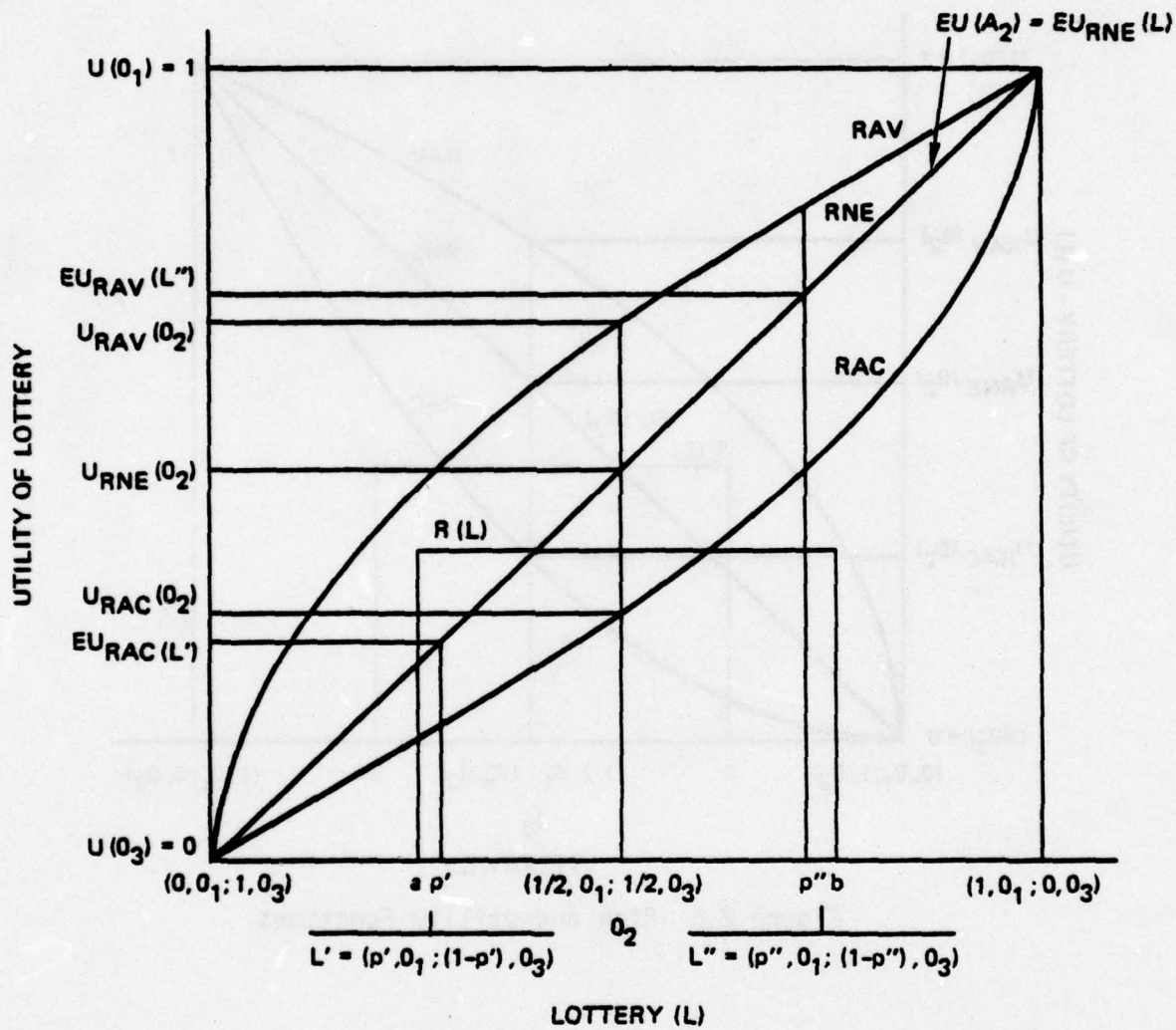
Figure 2.6 Alternative Probability Estimates Versus Outcome O_2

RAV decision maker estimates the probabilities as R(L), then

$$U_{RAV}(O_2) > EU(A_2) = 1/(b-a) \int_a^b U_{RAV}(L)dL$$

and the decision maker chooses A_1.

Last, suppose that some RNE decision maker estimates $PR(O_1/A_2) = q'$, then $U_{RNE}(O_2) > EU_{RNE}(L')$ and the decision maker chooses A_1. However, if he estimates $PR(O_2/A_2) = q''$, then $U_{RNE}(O_2) < EU_{RNE}(L'')$ and he chooses A_2. If some other RNE decision maker estimates the probabilities as R(L), then

$$U_{RNE}(O_2) = EU(A_2) = 1/(b-a) \int_a^b U_{RNE}(L)dL$$

and the decision maker is indifferent between A_1 and A_2.[17]

2.5 Risk and Uncertainty in Formal Deterrence Theory

Paralleling the earlier discussion of risk and uncertainty, two analogous questions are relevant to extant formal deterrence theory. First, Is the decision maker, before he is placed in a specific deterrence situation requiring a decision, a gambler or not? That is, Is he RAV, RNE or RAC? Second, Does the decision maker, regardless of his utility function, make specific estimates of $PR(V|A_2)$ and other probabilities or does he estimate some same range of numbers between 0 and 1 in which he believes the "true" probability to lie? The significance of these questions is the same as in the Section 2.2. These comments can be made clear by more explicit application to the earlier calculations on deterrence of strategic war.

Suppose that a potential aggressor has selected preference ordering I and is contemplating selection of A_2, which means he must evaluate a lottery

---

[17]Here we note that both q' and q" fall in the interval [a;b]. However, this does not necessarily have to be the case, but q' must be either less than a or greater than but close to a, that is, q' cannot be "too much" greater than a. The upper bound of q' depends upon the RAC decision maker's estimate of the width of [a;b] and the degree of convexity of his utility function. Analogous reasoning holds for q"; its lower bound, b; and the degree of concavity of the RAV decision maker's utility function.

between V and D. The key elements in this evaluation are his estimate of $PR(V|A_2)$ and the EU that this estimate generates. In other words, he must evaluate the lottery $(PR(V|A_2), V; (1-PR(V|A_2)), D)$. We note that as $PR(V|A_2)$ varies from 0 to 1, a series of lotteries is generated which vary from $(0,V; 1,D)$ to $(1,V; 0,D)$ and, by assumption of preference ordering I, the latter is his most preferred lottery and the former his least preferred. Thus, as earlier, it is possible to construct his utility function for all lotteries involving V and D, and, by the assumption of ordering I, $U(0,V;1,D) = 0$ and $U(1,V;0,D) = 1$. Further, we know that since SQ is his MRO, $U(SQ)$ must be between 0 and 1 and equivalent to the utility of some lottery between $(0,V;1,D)$ and $(1,V;0,D)$; that is, for some $PR(V|A_2)^* \in (0,1)$, $U(SQ) = PR(V/A_2)^* \times U(V) + [1 - PR(V/A_2)] \times U(D)$.

From this point on, the analysis and conclusions, with appropriate substitutions, are analogous to Section 2.2. Figure 2.7, which is Figure 2.6 with the requisite substitutions, displays graphically the key elements in our reformulated deterrence calculus. Appendix B displays utility and risk functions for all 13 utility functions accompanied by the attendant EU calculations. Other levels of deterrence, along with the accompanying calculations, are considered in Chapter IV below.
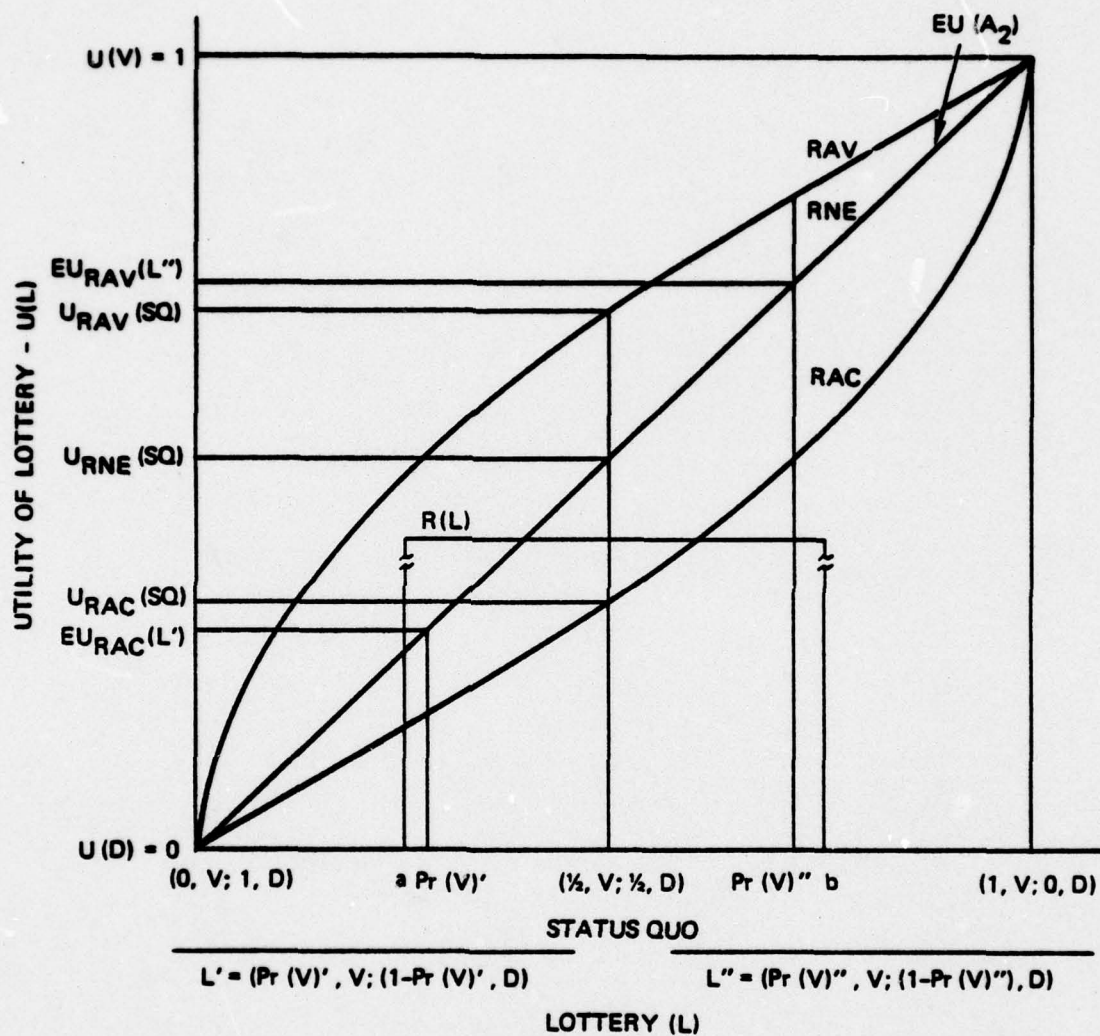
Figure 2.7 Alternative Probability Estimates Versus the Status Quo

III. A DYNAMIC CRISIS MODEL OF DETERRENCE

The classical model of deterrence examined above makes six basic assumptions which will be relaxed in this chapter to produce new conclusions that are applicable to dynamic crisis situations. This set of assumptions includes:

- the two main actors are a potential aggressor and a potential deterrer;

- the deterrer does not contemplate a preemptive strike under any set of circumstances;

- preferences and utilities of both actors will remain the same over time;

- attitudes of the actors toward risk will remain unchanged;

- each actor knows the opposing actor's preference ordering; and

- time is not a variable which will influence any actor's, or decision maker's, choice of actions.

From the first two assumptions, it follows that since there is no chance that the deterrer will strike preemptively, the potential aggressor, should he attack, does so purely out of a desire for aggrandizement and not from a fear of being attacked. It also follows from these two assumptions that the potential aggressor can achieve the status quo with certainty should he refrain from attacking.

In Section 3.1, a model of deterrence in crisis situations is developed in which both actors consider the possibility of a preemptive strike by each actor and against each actor. This new model will better depict the "typical" real world crisis situation than earlier models, and relaxes the first two assumptions of the classical model. Next to be considered in Section 3.2 are the possible effects of uncertainty about the opposing decision maker's preference ordering on the total decision environment. The fifth assumption of the classical model will no longer hold in this section; that is, each actor will not know the preference ordering of his opponent.

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Section 3.3 explores the implications of improved intelligence and early warning capabilities for the possibility of peaceful crisis management. The potential effects of time on strategic decision are covered in Section 3.4, while Sections 3.5 and 3.6 analyze the implications of changes in the preferences and attitudes toward risk of the two decision makers. The last three assumptions of the classic model are weakened in Sections 3.4, 3.5 and 3.6.

3.1   A Crisis Model of Deterrence

The fundamental difference between the model to be introduced in this section and the classical model of deterrence discussed previously is its symmetric game-theoretic nature.[1] The classical model involved a one-sided optimization problem; the potential aggressor compared his expected utility from initiating an attack with the utility of the status quo and then chose his course of action. While this formulation may do no serious harm to the picture of reality that is derived from a General Deterrence situation, the same cannot be said with respect to an Immediate Deterrence Crisis situation. One trademark of a crisis is the fear of attack that each side perceives. Consequently, each party considers a preemptive strike as an option in order to remove the possibility that it will be a victim. Thus, the outcome of either crisis decision--to attack or not to attack--is a lottery, lacking any certain option.

To incorporate these considerations into the model, let two parties involved in a crisis be designated A and B. A's possible actions are:

A_1: do not attack but respond if B attacks

A_2: attack

Let B_1 and B_2 be similarly defined for B. The sets of options for A and B are the same as those for the "potential aggressor" of Chapter II except that

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[1] For a discussion of the use and misuse of decision theory in game theoretic situations, see Steven J. Brams, "A Fundamental Limitation of Decision Theory in the Modeling of Game-Like Choice Situations," (unpublished paper, New York University 1977).

A_1 has been redefined as the conditional action "do not attack but respond if B attacks" acknowledging that B may also choose to attack. Thus, the parties in a crisis are considered to be both potential aggressors and deterrers.[2]

The alternatives and their consequences can be represented by the following matrix:

	B_1	B_2
A_1	α_{11}, β_{11}	α_{12}, β_{21}
A_2	α_{21}, β_{12}	α_{22}, β_{22}

Here α_{11} represents the payoff to A when both A and B do not attack; α_{21} the payoff to A when he launches a preemptive strike; α_{12} the payoff to A when he is attacked first; and, α_{22} the payoff when both parties attack simultaneously. Further, β_{21} is the payoff to B when he attacks first while β_{12} represents the payoff when B is the victim of a first strike. The definitions of β_{11} and β_{22} are the same as for α_{11} and α_{22}. Note that α_{12}, α_{21} and α_{22} (and β_{21}, β_{12}, β_{22}) all represent the utility of lotteries over victory and defeat, their differing values being attributed to the differing identities of the attacking party.

It should be clear that $\alpha_{21} > \alpha_{22} > \alpha_{12}$: that is, if a war is to be fought, A receives his highest payoff if he initiates the war; he gets his next highest payoff when the attacks occur simultaneously and his smallest payoff when he is the victim of a first strike. Thus, $\alpha_{21} \, P \, \alpha_{22} \, P \, \alpha_{12}$.

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[2]The model developed here follows closely that of Daniel Ellsberg, "The Crude Analysis of Strategic Choices," *American Economic Review*, 51 (1961), pp. 472-478, and Michael Nicholson, "Uncertainty and Crisis Behavior: An Illustration of Conflict and Peace Research," in C. F. Carter and J. L. Ford (eds.), *Uncertainty and Expectations in Economics* (Oxford, England: Blackwell's, 1972).

[3]For example, α_{22} = EU(SIMULTANEOUS ATTACK) = PR(V/SIMULTANEOUS ATTACK) x U(V/SIMULTANEOUS ATTACK) + PR(D/SIMULTANEOUS ATTACK) x U(V/SIMULTANEOUS ATTACK).

It may also be assumed that $\alpha_{11} > \alpha_{22} > \alpha_{12}$: that A gets a higher payoff from peace than from any war he does not initiate.[4] What may not be clear, especially to B, is whether $\alpha_{11} > \alpha_{21}$ or $\alpha_{11} < \alpha_{21}$--whether the payoff to A for a first strike by B is greater or less than the payoff to A for peace. $\alpha_{11} > \alpha_{21}$ would seem to be an accurate representation, for example, of Soviet payoffs concerning a general nuclear war. If $\alpha_{11} < \alpha_{21}$, then A would be better off initiating a first strike. Similar conclusions hold for B. We now examine the possible consequences of uncertainty with respect to A's and B's preferences between initiating a first strike and peace.

3.2   The Effects of Uncertainty

Suppose A's preference ordering is $\alpha_{11} \, P \, \alpha_{21} \, P \, \alpha_{22} \, P \, \alpha_{12}$ while B's is $\beta_{11} \, P \, \beta_{21} \, P \, \beta_{22} \, P \, \beta_{12}$ and each party knows the other's preference ordering. In this case both A and B have no need to fear an attack and therefore no need to launch a preemptive strike. It may be the case, however, that one or both parties are uncertain as to the other's preference ordering: specifically, whether they prefer peace or a first strike.

B may be uncertain as to whether $\alpha_{11} \, P \, \alpha_{21}$ or $\alpha_{21} \, P \, \alpha_{11}$. The fact that no war occurs at a given moment is not inconsistent with this uncertainty. For one thing, it takes time to prepare an attack, especially a non-nuclear one; when mobilization and deployment are necessary, a decision to attack cannot be followed immediately by the attack. Secondly, it takes time to collect and process relevant information or resolve group differences. When the national decision maker is a single individual, he may be uncertain as to whether $\alpha_{21} > \alpha_{11}$ or $\alpha_{11} > \alpha_{21}$. At the end of processing the information available, his conclusion may be that, in fact, α_{21} is greater than α_{11} and proceed to attack.

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[4]It may be that *after* a war the victim of an attack finds himself in a better position than before, possibly due in part to the "public relations" benefit of not having initiated the war. However, we are concerned with each party's pre-war expectations.

Suppose, for example, B estimates $\alpha_{21} > \alpha_{11}$ (α_{21} P α_{11}) to be the case with probability s and $\alpha_{11} > \alpha_{21}$ with probability (1-s).[5] Under what conditions will B attack purely due to fear of A's attacking first when, in fact, A has no interest in attacking B? To make the model symmetric, it is possible to assume that B's preference ordering is also in doubt; A believes β_{11} P β_{21} likely with probability r and β_{21} P β_{11} with probability (1-r). The overall situation then is that neither side desires war (even as the initiator) but fears the other does.

Looking at the problem from B's viewpoint, note that A will choose to attack (A_2) from direct self interest with probability s (the probability that α_{21} P α_{11}). Thus, the expected utility to B of not attacking (B_1) is:

$$EU(B_1) = (1-s)\,\beta_{11} + s\,\beta_{12}$$

while the expected utility of B_2 is:

$$EU(B_2) = (1-s)\,\beta_{21} + s\,\beta_{22}$$

B will, therefore, choose B_2 whenever:

$$EU(B_2) > EU(B_1)$$

or

$$(1-s)\,\beta_{21} + s\,\beta_{22} > (1-s)\,\beta_{11} + s\,\beta_{12}$$
$$s(\beta_{11} + \beta_{22} - \beta_{21} - \beta_{12}) + (\beta_{21} - \beta_{11}) > 0$$

The same argument applies to A. He will choose A_2 whenever

$$(1-r)\,\alpha_{21} + r\alpha_{22} > (1-r)\,\alpha_{11} + r\alpha_{12}$$

Now, if $\beta_{11} > \beta_{21}$ and s=0, then $EU(B_1) = \beta_{11} > EU(B_2) = \beta_{21}$ and B chooses B_1. However, when s > 0 it may be the case that

$$EU(B_2) > EU(B_1)$$

at which time B would choose to attack and his attack would be motivated purely by fear of an impending attack by A.

---

[5] When the actual preference ordering of the decision maker or group is undecided, s serves as B's prediction that α_{21} P α_{11} will be the result.

To illustrate, suppose $\beta_{11} = 4$, $\beta_{21} = 3$, $\beta_{22} = 2$, $\beta_{12} = 1$, and $s = 0.6$. Then,

$$EU(B_1) = .4\,(4) + .6\,(1) = 2.2$$

$$EU(B_2) = .4\,(3) + .6\,(2) = 2.4$$

and

$$EU(B_2) > EU(B_1).$$

This model can be further refined by acknowledging that each side may recognize that the *other* may attack not out of a desire for aggrandizement, *but out of fear of a preemptive strike.* Suppose B believes there is probability S that A will attack out of fear. Under these assumptions the overall probability perceived by B of an attack by A is $(s+S-sS)$.[6]

We now redefine our expected utility calculations so that:

$$EU^*(B_2) - EU^*(B_1) = (s+S-sS)(\beta_{11} + \beta_{22} - \beta_{21} - \beta_{12})$$
$$+ (\beta_{21} - \beta_{11})$$

with S being interpreted as B's probability estimate that A believes EU $(B_2) > 0$ and will thus attack.

With resonably high degrees of information, one would expect that the value of S is clearly related to whether $EU(B_2)$ is in fact positive or negative. If $EU(B_2)$ is clearly negative, then S should be close to zero and $EU^*(B_2) \approx EU(B_2)$; if $EU(B_2)$ is clearly positive, then S will be close to one and $EU(B_2) \approx (\beta_{21} - \beta_{11})$. To illustrate, suppose that the relationship between $EU(B_2)$ and $EU^*(B_2)$ is that presented in Figure 3.1; then the relationship between $EU(B_2)$ and $EU^*(B_2)$ will be that depicted in Figure 3.2.

Note that $EU^*(B_2) \geq EU(B_2)$ since $(s+S-sS) \geq s$. Hence the consideration of B that A may perceive a positive probability of a preemptive attack by A makes it more likely that B will attack.

---

[6] Given two events, E_1 and E_2, the probability that one or the other or both will occur is:

$$PR(E_1 \cup E_2) = PR(E_1) + PR(E_2) - PR(E_1E_2)$$
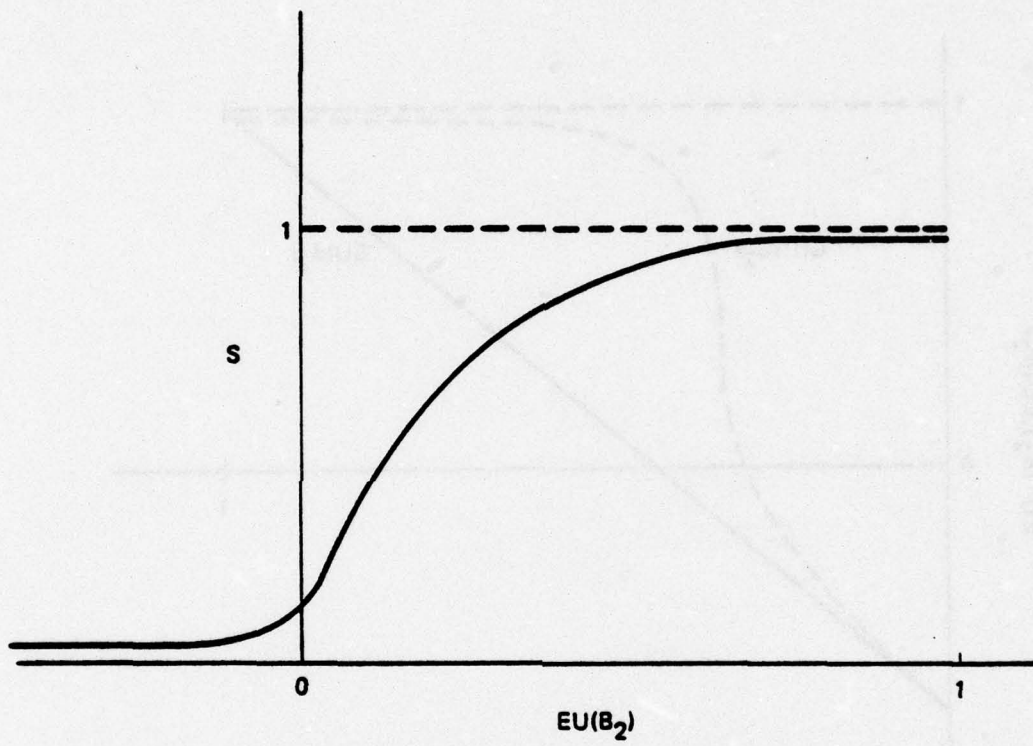
Figure 3.1 Relationship Between S and $EU(B_2)$.
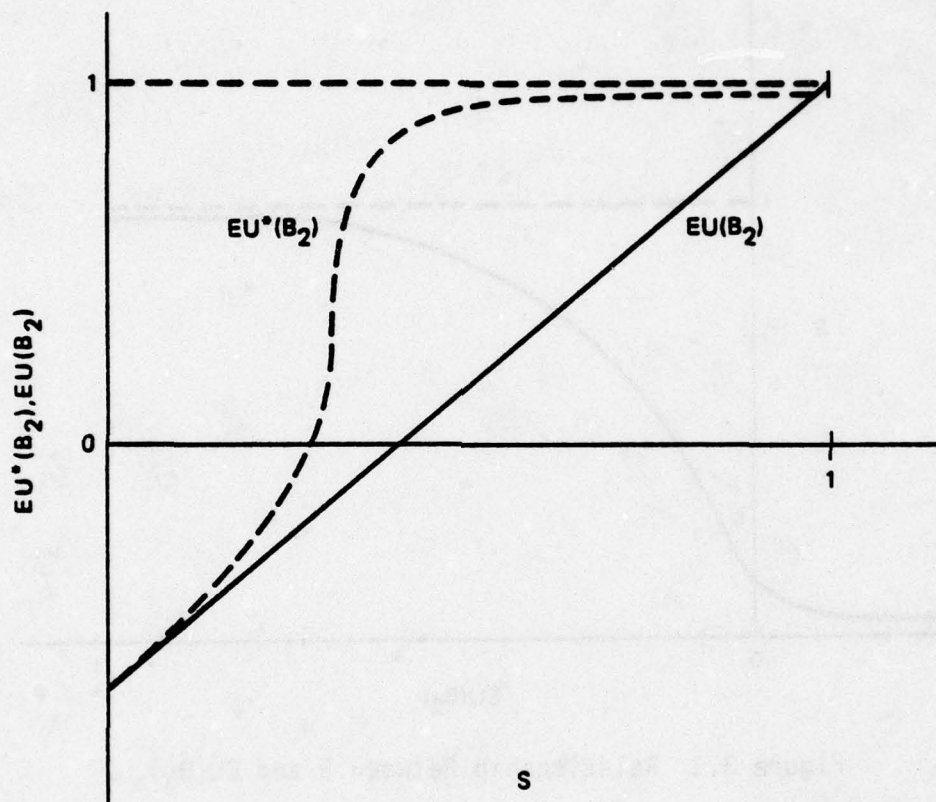
Figure 3.2   Relationship Between S and $EU^*(B_2)$, $EU(B_2)$

3.3 Early Warning Capabilities and the Maintenance of Peace

In the section above we noted that high states of information would make it likely that the value of S would be closely related to whether $EU(B_2)$ is positive or negative. Thus, high states of information could prevent the outbreak of war through fear. In this section we demonstrate how improved early warning capabilities can prevent the outbreak of war even if both sides prefer to initiate a conflict than to remain at peace and become a victim. Suppose α_{21} P α_{11} (for A) and β_{12} P β_{11} (for B) and recall that the matrix representation of the possible actions and their consequences was:

	B_1	B_2
A_1	α_{11}, β_{11}	α_{12}, β_{21}
A_2	α_{21}, β_{12}	α_{22}, β_{22}

The game defined by the above matrix where $\alpha_{21} > \alpha_{11} > \alpha_{22} > \alpha_{12}$ and $\beta_{21} > \beta_{11} > \beta_{22} > \beta_{12}$ is known as Prisoner's Dilemma.[7] Given no information as to the likelihood of an opponent's actions, both A and B would rationally choose to attack since such a strategy choice assures a higher payoff than each would achieve by not attacking *regardless* of the other's actions. If A chooses A_2 and B does not attack, then A gets α_{21} whereas he would have only received α_{11} had he not attacked. If B does attack, A receives α_{22} whereas he would have only received α_{12} had he refrained from attacking. The reasoning is similar for B. If, however, both rationally choose to attack, then the result is the payoff α_{22}, β_{22} which *both* parties find inferior to the payoff α_{11}, β_{11} of peace.

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[7] See A. Rapoport and A. M. Chammah, *Prisoner's Dilemma: A Study in Conflict and Cooperation* (University of Michigan Press, Ann Arbor, Michigan, 1965).

A suggested solution to this dilemma involves incorporating probabilities into the decision problem and allowing each party to engage in "conditional cooperation."[8] Here, the probability numbers will reflect, not each party's estimates of what the other will do, but rather each party's ability to *detect* what the other is doing. It is easily demonstrated that if the early warning capabilities are sufficiently sensitive to detect accurately the other party's intentions, then they will both find it rational to abstain from attacking.

Assume B adopts a choice rule of *conditional cooperation*. Specifically, B refrains from attacking if he believes A will also refrain from attacking. While B would prefer to launch a first strike, he realizes that if A has a sufficiently sensitive early warning capability an attempted first strike will turn into a simultaneous attack, which B finds inferior to the status quo. Let v be the probability that B can correctly estimate A's intended action, whether it is A_1 or A_2, and (1-v) the probability that this estimate of A's intended action will be incorrect. The expected utility to A of choosing A_1 (not attack) is therefore:

$$EU(A_1) = v\, \alpha_{11} + (1-v)\, \alpha_{12}$$

The expected utility of choosing A_2 is:

$$EU(A_2) = (1-v)\, \alpha_{21} + v\, \alpha_{22}$$

A will choose to not attack whenever

$$EU(A_1) > EU(A_2)$$

or

$$v\, \alpha_{11} + (1-v)\, \alpha_{12} > (1-v)\, \alpha_{21} + v\, \alpha_{22}$$

$$v(\alpha_{11} - \alpha_{22}) > (1-v)\, (\alpha_{21} - \alpha_{12})$$

$$\frac{v}{(1-v)} > \frac{(\alpha_{21} - \alpha_{12})}{(\alpha_{11} - \alpha_{22})}$$

[8] Steven J. Brams, "Newcomb's Problem and Prisoner's Dilemma," *Journal of Conflict Resolution*, 19(1975), pp. 596-612.

The above inequality will be satisfied whenever v is "sufficiently high;" that is, when B can detect with sufficient accuracy A's intended action. The logic from A's viewpoint is simple: if A plans to attack and v is "sufficiently high," then B will very likely discover his plans and the ultimate result will be a "simultaneous" or virtually simultaneous attack producing an outcome (α_{22}) that A finds inferior to peace (α_{11}). Thus, it is to A's advantage, given B's conditional cooperation, to refrain from attacking.

To illustrate, suppose

$$\alpha_{21} = 4$$
$$\alpha_{11} = 3$$
$$\alpha_{22} = 2$$
$$\alpha_{12} = 1$$

then

$$\frac{v}{(1-v)} > \frac{(4-1)}{(3-2)}$$

$$\frac{v}{1-v} > 3$$

$$v > 3-3v$$
$$4v > 3$$
$$v > .75$$

In this case, if B can detect with greater than 75 percent accuracy A's planned action, A maximizes his expected utility by not attacking.

Likewise, suppose player A can correctly detect B's choice of actions with probability w. B's expected utility from B_2 will then be:

$$EU(B_2) = (1-w)\,\beta_{21} + w\beta_{22}$$

while his expected utility from B_1 is:

$$EU(B_1) = w\beta_{11} + (1-w)\,\beta_{12}$$

B will find it advantageous not to attack whenever:

$$\frac{w}{(1-w)} > \frac{(\beta_{21} - \beta_{12})}{(\beta_{11} - \beta_{22})}$$

In summary, if one player adopts a conditionally cooperative choice rule and can predict the other's strategy choice with sufficient accuracy, the other player maximizes his own expected utility by also cooperating, provided he can detect his opponent's true intentions with a sufficiently high probability. The implications of this result for any outside party who wishes to prevent an outbreak of war between A and B even though they prefer to strike the first blow is clear; increase the intelligence capabilities of *both* A and B so they can detect the intended operations of each party with "sufficiently high" accuracy, and insure that at least one of the parties adopt a choice rule of conditional cooperation.

3.4 Time as a Variable

As previously noted, time is a variable that has largely been excluded from consideration in deterrence theory. In the General Deterrence situations listed in Table 2.3, this ommission may not be of major consequence. In crisis situations, however, time is a significant complicating factor. Numerous possible effects of the time element on strategic interactions and decisions can be conceived.

At the most elementary level there is the observation that if one has to decide very quickly about some issue, it is quite possible his judgment will be different than if he had more time for thought. The time needed to properly evaluate all the alternative courses of action, the probabilities of various outcomes and other considerations does not exist in a crisis situation.

More importantly, a decision maker will be forced by the time factor to make decisions before he has either full or adequate information concerning the state of the world. Suppose B feels that it is essential for him to attack preemptively when $(s+S-sS) > L$, the level of $(s+S-sS)$ for which $EU^*(B_2) > EU^*(B_1)$ for the first time. Logically then, an attack would be expected only after L has been passed. If, however, B waits until $EU^*(B_2) > EU^*(B_1)$, he may find himself with inadequate time to prepare and execute a preemptive attack; A may beat him to it. This possibility forces us to

consider, in addition to his probability estimate of aggression by A $(s+S-sS)$, the rate of change of $(s+S-sS)$. If $\frac{\partial(s+S-sS)}{\partial t}$ (where t is time) is high, $(s+S-sS)$ might quickly exceed L and approach 1 before B can prepare and execute a preemptive strike. This problem is illustrated by Figure 3.3.

A crisis begins somewhere between times t_0 and t_1. It may be the case that a decision to preempt can only be implemented prior to time t_3 if made no later than t_1. If the true state of affairs is described by curve I and B does not make a decision prior to time t_1 (when I is still for below L), then B will be the victim of a surprise attack at t_3. On the other hand, an "irreversible" decision[9] at t_1 to do so may result in an outbreak of hostilities at time t_3 even though the probability of an attack has shrunk to 0 (curve II).

Another problem is indicated by curve III which rises and then levels off asymptotic to L. The decision maker may not know the numerical value for $\frac{\partial(s+S-sS)}{\partial t}$ or whether $\frac{\partial^2(s+S-sS)}{\partial t^2}$ is positive or negative. Thus "caution" may lead him to act as if curve I was the true state of affairs when in fact III accurately describes the situation.

It is possible to further distinguish between these reasons for preemption. When $(s+S-sS) > L$ and preemption occurs, that act is simply labeled preemption. However, when $(s+S-sS) < L$ but $\frac{\partial(s+S-sS)}{\partial t}$ is considered to be sufficiently high to prompt preemption, that act is labeled "anticipatory preemption;" the preempter anticipates $(s+S-sS)$ will pass L but knows that if the present rate (or approximate rate) of increase continues he will be unable to preempt in the time interval between $(s+S-sS)$ reaching L and its reaching 1.

An additional manner in which time may directly affect a decision maker's choice involves the value and state of the information he possesses.

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[9] A nation's decision to mobilize its forces, for example, may trigger a similar decision by its opponent. Once both nations have mobilized, war may become virtually inevitable. See Barbara Tuchman, *The Guns of August* (New York: Macmillan, 1961).
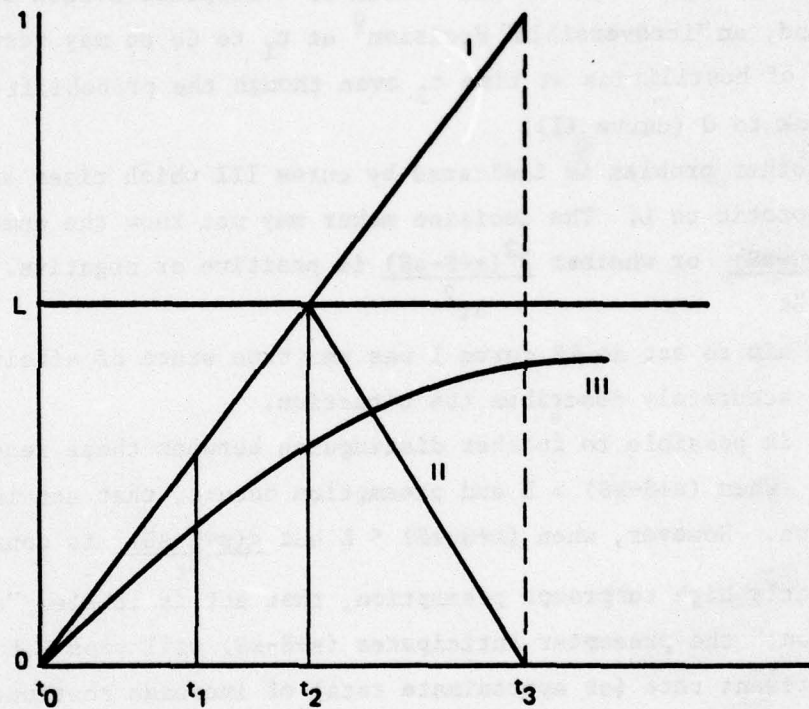
Figure 3.3 Alternative Relationships Between Time and the
Probability of Being Attacked

At any given time a decision maker is in possession of certain amounts of intelligence and other information concerning the enemy's military deployments and capabilities. With the passage of time, however, and especially under crisis conditions, the time sensitive value of that information declines since its currency declines: planes will have been dispersed, camouflage introduced, and troops moved. Thus, the information at time t_0 has more value in aiding a first strike than the same information at time t_1. This relationship between information value and time is captured in Figure 3.4.

Similarly, equivalent expenditures of resources at time t_1 will produce information of less value in aiding a preemptive strike at time t_1 than information obtained at time t_0 would have been in aiding a first strike at time t_0. Since targets will be further dispersed, better hidden, and so forth in a crisis situation, they will be that much more difficult to locate, putting greater demands on intelligence collection systems. Additionally, while each side had the whole pre-crisis period to determine the location of targets, the crisis period is much shorter. A decision maker must incorporate these elements in his decision process. If he waits too long to preempt, he may find himself with out-of-date information and inadequate intelligence whose use (in a preemptive strike) could lead to disaster but which, if not used, could also lead to disaster. He is on the horns of a dilemma, and must balance the tradeoff between the declining value of his information and his desire to avoid conflict.

3.5   Changes in the Values of the Variables in the Decision Calculus

The present section, as well as section 3.6, examines the dynamic aspects of the General Deterrence situation, described by the calculus in Chapter II. Note that changing values in the variables can represent either actual changes in the variables for the decision maker, a change in decision makers, or a shifting power alignment in a group of decision makers.

Specifically, we investigate the impact on $EU(A_1)$, $EU(A_2)$, and the decision maker's resulting decision of changes in the values of each variable in the calculations. In order to keep the initial analysis within
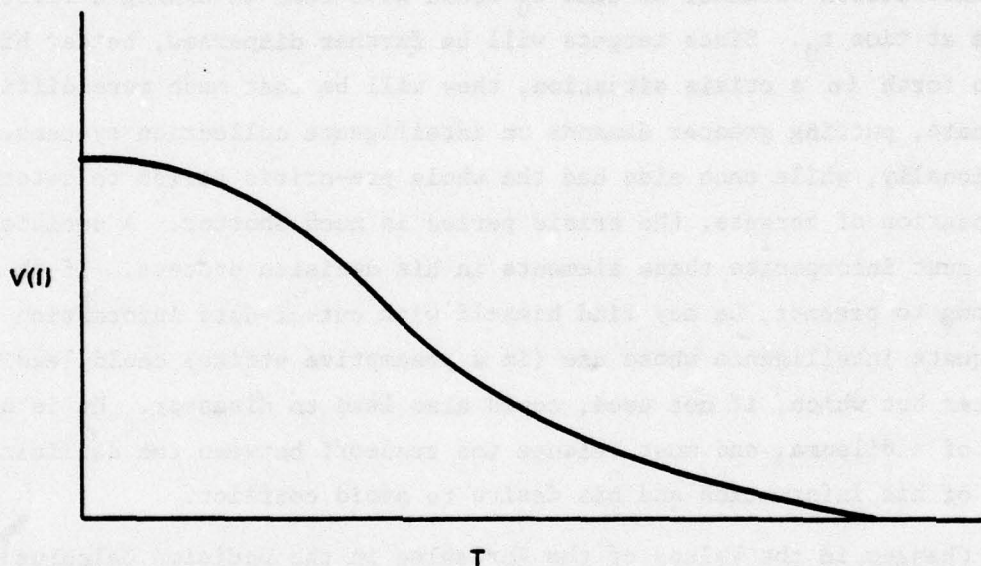
Figure 3.4 Decline in the Value of Information

manageable boundaries, it is necessary to add two additional restrictions; namely, the variables change at constant rates and these rates are equivalent across all variables.

With regard to the decision maker's preference ordering for outcomes, it has previously been noted that there are thirteen distinct, logical possibilities, as illustrated in Table 2.1, above. Here, there are two relevant dymanic aspects:

(1) a change in the decision maker's ordering itself, e.g., from I to VIII; and

(2) given a specific ordering, variations in his evaluation of the middle ranked outcome (MRO) versus the others, which can occur in only six of the thirteen orderings--I, IV, VI, VIII, X and XII.

Possible changes in the decision maker's ordering is relatively straightforward to those six orderings with a clear middle ranked outcome, while orderings containing an indifference are more problematic but can be dealt with. For example, in ordering II, either O_2 or O_3 can become the middle ranked outcome although both cannot decrease in value; one or the other must increase. If O_2 increases, ordering II becomes I; if O_3 increases, II becomes IV; if both increase, II remains II; but if both increase sufficiently, II may become XIII or IX. Table 3.1 summarizes the relevant logical possibilities.

In six orderings (I, IV, VI, VIII, X and XII), changes in the normalized utility of each middle ranked outcome must be considered. If changes in the utility of the MRO, U_{MRO}, are regarded as a function of time, there are three relevant possibilities for $t_1 > t_0$: (1) $U_{MRO}(t_1) = U_{MRO}(t_0)$; (2) $U_{MRO}(t_1) > U_{MRO}(t_0)$; and (3) $U_{MRO}(t_1) < U_{MRO}(t_0)$. Table 3.2 summaries these possibilities and their attendant impact on EU calculations. The logical relationships from which changes in each EU calculation were derived are outlined in Appendix A.

With regard to a decision maker's utility function, it is important to note both the type of utility function that characterizes a decision maker, that is, RAV, RNE and RAC; and that for the RAV and RAC type, whether

TABLE 3.1

CHANGES IN PREFERENCE ORDERINGS

Preference Ordering	Outcome(s) Subject to Change	Direction of Change	Preference Ordering After Change
II	O_2	increase	I
II	O_3	increase	IV
III	O_1	decrease	XII
III	O_2	decrease	I
V	O_1	decrease	VI
V	O_3	decrease	IV
VII	O_1	increase	VI
VII	O_2	increase	VIII
IX	O_2	decrease	VIII
IX	O_3	decrease	X
XI	O_1	increase	XII
XI	O_3	incrase	X
XIII	O_1	decrease	IX
XIII	O_2	decrease	V
XIII	O_3	decrease	III
XIII	O_1,O_2	decrease	VII
XIII	O_1,O_3	decrease	XI
XIII	O_2,O_3	decrease	II
XIII	O_1^*,O_2	decrease	VIII
XIII	O_1,O_2^*	decrease	VI
XIII	O_1,O_3	decrease	X
XIII	O_1^*,O_3	decrease	XII
XIII	O_2^*,O_3	decrease	IV
XIII	O_2,O_3^*	decrease	I

*decreases at a faster rate.

TABLE 3.2
POSSIBLE CHANGES IN UTILITY OF MIDDLE RANKED OUTCOME

Preference Ordering	Change in U_{MRO}	Net Change in $EU(A_1)$	Net Change in $EU(A_2)$
I	none	none	none
I	increase	increase	none
I	decrease	decrease	none
IV	none	none	none
IV	increase	none	increase
IV	decrease	none	decrease
VI	none	none	none
VI	increase	none	increase
VI	decrease	none	decrease
VIII	none	none	none
VIII	increase	increase	none
VIII	decrease	decrease	none
X	none	none	none
X	increase	none	increase
X	decrease	none	decrease
XII	none	none	none
XII	increase	none	increase
XII	decrease	none	decrease

the decision maker becomes more or less risk averse over time. For the RAV decision maker there are three possibilities. If for all t_0, t_1 such that $t_1 > t_0$, $|U_{RAV}(O_2)_{t_0} - EU(A_2)_{t_0}| = |U_{RAV}(O_2)_{t_1} - EU(A_2)_{t_1}|$, then his degree of risk adversity is unchanged.

If $|U_{RAV}(O_2)_{t_0} - EU(A_2)_{t_0}| < |U_{RAV}(O_2)_{t_1} - EU(A_2)_{t_1}|$, then his degree of risk adversity has increased. If $|U_{RAV}(O_2)_{t_0} - EU(A_2)_{t_0}| > |U_{RAV}(O_2)_{t_1} - EU(A_2)_{t_1}|$, then his degree of risk adversity has decreased.

For the RAC decision maker there are also three possibilities. If $|U_{RAC}(O_2)_{t_0} - EU(A_2)_{t_0}| = |U_{RAC}(O_2)_{t_1} - EU(A_2)_{t_1}|$, then his degree of risk adversity is unchanged. If $|U_{RAC}(O_2)_{t_0} - EU(A_2)_{t_0}| < |U_{RAC}(O_2)_{t_1} - EU(A_2)_{t_1}|$, then his degree of risk acceptance has increased. If $|U_{RAC}(O_2)_{t_0} - EU(A_2)_{t_0}| > |U_{RAC}(O_2)_{t_1} - EU(A_2)_{t_1}|$, then his degree of risk acceptance has decreased. Lastly, note that for the RNE decision maker there is only one possibility, namely, no change; in other words, whether or not a decision maker is RAV, RNE or RAC and the degree to which he is are directly proportional to the curvature of his utility function for lotteries between O_1 and O_3.

The magnitude of a decision maker's probability estimates can be approximated by three possibilities if each type of estimates for $PR(O_1/A_2)$, we have:

(1) $PR(O_1/A_2)_{t_0} = PR(O_1/A_2)_{t_1}$;

(2) $PR(O_1/A_2)_{t_0} > PR(O_1/A_2)_{t_1}$;

(3) $PR(O_1/A_2)_{t_0} < PR(O_1/A_2)_{t_1}$.

For R(L) estimates, the situation is a bit more complicated. Recall that R(L) is a probability distribution over $[a;b]$, and $R(L) = 1/(b-a)$. Thus, changes in the width of $[a;b]$ have an inverse impact on the magnitude of R(L); e.g., if $(b-a)$ decreases, then R(L) increases. Keeping this consideration in mind, the three possibilities are:

(1) if $[a;b]_{t_0} = [a;b]_{t_1}$, then $R(L)_{t_0} = R(L)_{t_1}$;

(2) if $[a;b]_{t_0} > [a;b]_{t_1}$, then $R(L)_{t_0} < R(L)_{t_1}$;

(3) if $[a;b]_{t_0} < [a;b]_{t_1}$, then $R(L)_{t_0} > R(L)_{t_1}$.

The dynamic considerations affecting a decision maker's utility function and probability estimates greatly multiply the number of logical decision situations to be considered in the model.[10]

3.6 Application to Deterrence Theory

In this section we are interested in applying the results of Section 3.5 to deterrence theory. Of special interest is a potential aggressor's possible switch from a continuing decision of A_1 (deterrence is successful) to one of A_2 (deterrence fails).

Recall that the condition for successful deterrence is

$$EU(A_1) > EU(A_2)$$

or

$$EU(A_1) - EU(A_2) > 0.$$

This expected utility differential (EUD) is a function of the magnitude of the two EU's. The probability that a potential aggressor continued to select A_1, $PR(A_1)$, is a function of the magnitude of EUD. Graphically, we can continue this function to be either a step function, as in Figure 3.5.a or, more realistically, owing to the possibility of miscalculation by a potential aggressor, some monotonic function, as in 3.5.b.

If $PR(A_1)$ increased over time, we can say that deterrence is strengthened; if $PR(A_1)$ remains unchanged, deterrence succeeds to the same degree;

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[10] Rather than taking up extra space here, the factors relevant to each logically possible situation and their net impact on EU calculations are summarized in Appendix A. Here we note that after redundant situations are eliminated, there are 1179 logically possible decision situations to be examined. In order to do so and to tie these logical possibilities more closely to deterrence calculations, a computer program has been developed capable of selecting and analyzing each situation.
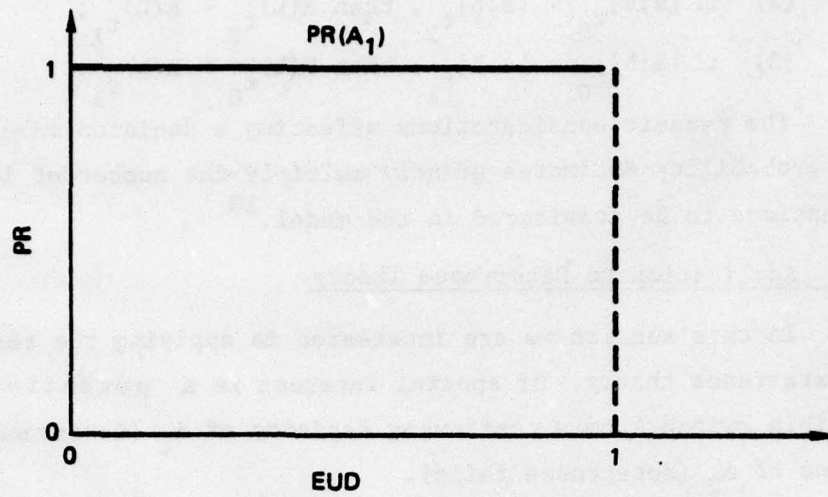
a. PR(A_1) as a Step Function
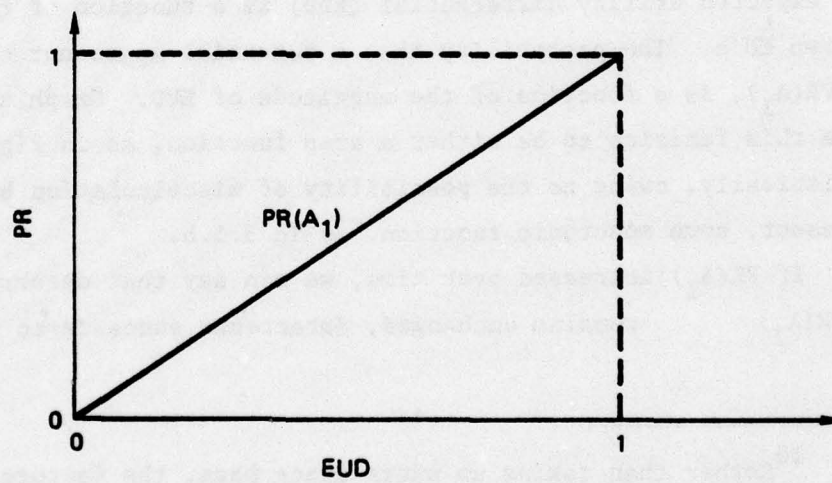
b. PR(A_1) as an Increasing Function

Figure 3.5 PR(A_1) As a Function of EUD

if $PR(A_1)$ decreases, then deterrence has been weakened; and if $PR(A_1)$ continues to decrease, deterrence will fail at some point. In terms of the six-fold typology discussed in Table 2.3, a situation is one of general deterrence if $PR(A_1)$ is constant. If $PR(A_1)$ changes, then the general deterrence situation may change as a result of a potential aggressor's re-evaluation of $EU(A_1)$ and $EU(A_2)$. If $PR(A_1)$ increases, then deterrence is reinforced and the general deterrence situation is more stable. However, if $PR(A_1)$ decreases, then deterrence is weakened and the situation moves to a less stable situation of immediate deterrence.

With respect to changes in EUD, there are eleven logical possibilities:

(1) if $EU(A_1)_{t_0} = EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} = EU(A_2)_{t_1}$, then $EUD_{t_0} = EUD_{t_1}$ and $PR(A_1)_{t_0} = PR(A_1)_{t_1}$;

(2) if $EU(A_1)_{t_0} < EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} < EU(A_2)_{t_1}$ and both increase at the same rate, then

$$EUD_{t_0} = EUD_{t_1} \text{ and } PR(A_1)_{t_0} = PR(A_1)_{t_1};$$

(3) if $EU(A_1)_{t_0} < EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} < EU(A_2)_{t_1}$ and $EU(A_1)$ increases at a faster rate, then

$$EUD_{t_0} < EUD_{t_1} \text{ and } PR(A_1)_{t_0} < PR(A_1)_{t_1};$$

(4) if $EU(A_1)_{t_0} < EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} < EU(A_2)_{t_1}$ and $EU(A_2)$ increases at a faster rate, then

$$EUD_{t_0} > EUD_{t_1} \text{ and } PR(A_1)_{t_0} > PR(A_1)_{t_1};$$

(5) if $EU(A_1)_{t_0} > EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} > EU(A_2)_{t_1}$ and both decrease at the same rate, then

$$EUD_{t_0} = EUD_{t_1} \text{ and } PR(A_1)_{t_0} = PR(A_1)_{t_1};$$

(6) if $EU(A_1)_{t_0} > EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} > EU(A_2)_{t_1}$ and

$EU(A_1)$ decreases at a faster rate, then

$$EUD_{t_0} > EUD_{t_1} \text{ and } PR(A_1)_{t_0} > PR(A_1)_{t_1};$$

(7) if $EU(A_1)_{t_0} > EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} > EU(A_2)_{t_1}$

and $EU(A_2)$ decreases at a faster rate, then

$$EUD_{t_0} < EUD_{t_1} \text{ and } PR(A_1)_{t_0} < PR(A_1)_{t_1};$$

(8) if $EU(A_1)_{t_0} = EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} < EU(A_2)_{t_1}$,

then $EUD_{t_0} > EUD_{t_1}$ and $PR(A_1)_{t_0} > PR(A_1)_{t_1};$

(9) if $EU(A_1)_{t_0} = EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} > EU(A_2)_{t_1}$

then $EUD_{t_0} < EUD_{t_1}$ and $PR(A_1)_{t_0} < PR(A_1)_{t_1};$

(10) if $EU(A_1)_{t_0} < EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} = EU(A_2)_{t_1}$,

then $EUD_{t_0} < EUD_{t_1}$ and $PR(A_1)_{t_0} < PR(A_1)_{t_1};$

(11) if $EU(A_1)_{t_0} > EU(A_1)_{t_1}$ and $EU(A_2)_{t_0} = EU(A_2)_{t_1}$,

then $EUD_{t_0} > EUD_{t_1}$ and $PR(A_1)_{t_0} > PR(A_1)_{t_1}.$

These possibilities indicate the integral and complex relationships which the probabilities over alternative courses of actions, and the changes in them, have for the expected utilities of these actions. At the theoretical level, this analysis appears to make a good deal of sense. It remains, however, to demonstrate the empirical validity of such a model in real world decision situations and the potential for utilizing the model in the aid of decision makers faced with potential crisis situations.

IV. EMPIRICAL CONSIDERATIONS

The foregoing analysis and discussion has not been intended as a description of the processes by which decision makers actually reach policy choices. Its purpose was twofold; to construct a set of abstract assumptions which characterize key aspects of the real world and to explore the ramifications of these assumptions for decision making behavior in the abstract, in order to more clearly delineate empirical factors relevant to that behavior. The present chapter examines some real world implications of these assumptions and their ramifications, incorporating both their shortcomings in analysis of behavior and variables relevant to the decision factors identified in the model above.

4.1 Rational Choice in Deterrence

The problem raised by the assumption of rational decision making has three significant aspects: first, the problem of "false personification" in examining individual versus group decisions; second, the issue of whether or not individuals and groups behave in a "rational" manner; and, third, the amount of information available to the decision makers.[1]

While recognizing that individual and group decision processes differ in a number of important respects, the question is not a central problem of our analysis. The model as proposed and subsequently implemented is "neutral" vis-a-vis this question; namely, the decision maker can be either an individual or a group. We believe that the issue is not one relating to the rationality or irrationality of individuals versus groups, but the degree of group rationality as a function of the rationality of individuals in the group.

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[1]For a recent discussion of these aspects in the context of formal deterrence theory, see Patrick M. Morgan, *Deterrence, A Conceptual Analysis* (Beverly Hills: Sage Publications, 1977). An alternate set of assumptions about decision makers, called cybernetic decision theory, is discussed in rudimentary form by John Steinbruner, "Beyond Rational Deterrence: The Struggle for New Conceptions," *World Politics*, 28(1976), pp. 223-245.

In the Cuban missile crisis, for example, President Kennedy gave his advisors the objective of designing a course of action that would effect removal of Soviet missiles from Cuba. In their subsequent deliberations, Kennedy's advisors behaved in reasonable conformity with our assumptions regarding rational behavior: they examined a number of possible outcomes of the situation; they weighed the benefits versus costs of each outcome in order to establish some rough preferences for them; they examined various possible courses of action they believed would effect the removal of Soviet missiles; they made some rough estimates of the probability that each action would achieve Kennedy's goal while simultaneously weighing the benefits and costs of each action; and finally, they recommended a course of action, the quarantine, they believed had a reasonable chance of success at a minimal cost.[2]

Although individual versus group rationality is not a central concern of the present analysis, three aspects of our model are important in this context:

o   What processes are used in the construction of preference order-
         ings for outcomes?

o   What type of probability estimates are made?

o   What are the decision maker's attitudes toward risk?

With regard to the rationality assumption itself, it is possible to note that decision makers cannot be divided into mutually exclusive cate-gories of rational and irrational. As has been exhaustively discussed and analyzed, individuals and groups display varying degrees of rational-ity depending upon a number of factors contained in the specific

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[2]See Graham Allison, *Essence of Decision: Explaining the Cuban Missile Crisis* (Boston: Little, Brown, 1971); Alexander L. George and Richard Smoke, *Deterrence in American Foreign Policy: Theory and Practice* (New York: Columbia University Press, 1974), pp. 447-499; Robert F. Kennedy, *Thirteen Days* (New York: Norton, 1969); Theodore C. Sorensen, *Decision-Making in the White House* (New York: Columbia University Press, 1963).

situation.[3] In national security deterrence situation decisions, two factors encourage decision makers to behave in a "more rational" manner than they might in numerous other contexts, but we recognize that their relevance varies from situation to situation.

First, the *importance* of the decision, as related to the possible consequences of action and the potential costs of miscalculation or errors, *encourages* rational decision making. This is one significant difference between decisions involving outcomes in laboratory experiments or consumer studies and those that may involve the continued survival of the nation. National security decision makers are periodically faced with decisions associated with perceived significant costs which in turn encourage them to gather relatively large quantities of relevant information, more carefully scrutinize this information, and give adequate consideration to possible outcomes, their potential actions and consequences of these actions, in order to minimize the probability of miscalculation or error.

Second, the *fiduciary* nature of a national security decision maker's role encourages rational behavior. Again in the Cuban missile crisis example, one course of action open to President Kennedy was *no* action, allowing the Soviets to successfully alter the status quo by placing Soviet missiles in Cuba. This course of action was rejected at the outset by both Kennedy and a number of key advisors. One factor relevant to this rejection

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[3]For a summary of relevant literature, see William H. Riker and Peter C. Ordeshook, *An Introduction to Positive Political Theory* (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1973). See also Baruch Fischhoff and Paul Slovic, *On the Psychology of Experimental Surprises: Outcome Knowledge and the Journal Review Process,* Technical Report DDI-6 (Eugene: Oregon Research Institute, August 1976); J. S. A. Kaplowitz, "An Experimental Test of a Rationalistic Theory of Deterrence," *Journal of Conflict Resolution,* 17(1973), pp. 535-572; Charles R. Plott and Michael Levine, "On Using the Agenda to Influence Group Decision: Theory, Experiments and Application," *Social Science Working Paper No. 66* (Pasedena: California Institute of Technology, April 1975); Paul Y. Hammond, Charles R. Plott, and Abraham R. Wagner, *Social Choice and Soviet Strategic Decision Making: The Influence of Group Processes on Policy and the National Command Authority (U),* AAC-TR-5401-77 (Marina del Rey: Analytical Assessments Corporation, May 1977).

was Kennedy's apparent belief that failure to act would precipitate his impeachment, and justifiably so. In other words, Kennedy, as a fiduciary, felt that doing nothing constituted an impeachable offense under the Constitution.[4] On the Soviet side, Khruschev's behavior and the resulting Soviet "humiliation" in the crisis were apparently contributing factors in his downfall two years later.

Last, as noted, numerous critiques of the rational choice approach point out that such models place unrealistic information gathering and processing demands on decision makers. Such a view, however, places all analyses of real world decision making in a paradoxical situation. On the one hand, we find real world decision makers deciding on the basis of limited information and face the problem of explaining why those decisions were made, while on the other, there is growing evidence from both laboratory experiments and computer simulations that all decisions in finite time frames are inevitably made on the basis of limited information with uncertainty inherent in every decision situation.[5]

In short, as all real world decisions are based on limited information, and the analysis has demonstrated that, in principle, such considerations can be included in formal deterrence theory, we do not regard uncertainty as an insurmountable obstacle to empirical application of the model presented.

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[4]It is worth noting that decision makers can easily misjudge the domestic reaction to crisis outcomes and/or foreign policy initiatives. For example, following the Bay of Pigs fiasco, Kennedy's popularity registered a significant increase. See John E. Mueller, *Wars, Presidents and Public Opinion* (New York: John Wiley and Sons, 1973), pp. 210-213.

[5]See, for example, M. J. Barrett *(et al.)*, *Information Processing Types and Simulated Production Decision Making* (Minneapolis: University of Minnesota Management Information Systems Research Center, Graduate School of Business Administration, May 1973); B. A. Sproule and J. M. Sproule, "A System Simulation of Information Overload Conditions in Decision Making," paper delivered at the International Communication Association Annual Conference, April 1976; Charles R. Plott, "Experimental Examination of Mathematical Models of Group Decision Processes" (unpublished paper, California Institute of Technology, 1977).

4.2 Preference Orderings and Utility Functions

A more important difficulty is present in the assumption that the possible outcomes of a deterrence situation can be collapsed into three categories. There are few situations in which this would not be a gross distortion of reality. For example, the situation concerning Korea prior to the outbreak of war in June 1950 would be one of the rare instances in which this assumption does *not* present too gross a distortion.

In the Korean case there appear to have been three main outcomes which implicitly occupied the attention of the principal actors in the years prior to the war:

o O_1 - a unified, non-communist (presumably democratic, pro-American) Korea;

o O_2 - continued partition into a communist north and non-communist south; and

o O_3 - a unified, communist (presumably pro-Soviet, later pro-Chinese) Korea.

On the other hand, the current Middle East situation contains a multiplicity of actors pursuing a multiplicity of goals, suggesting a considerably larger number of potential outcomes.

Thus, we would expect that, regardless of the number of actors, most real world deterrence situations contain a multiplicity of objectives being pursued. The distortion of reality this assumption entails can be reduced by viewing each deterrence situation as represented by three *bundles* of objectives formulated prior to or at the outbreak of a crisis.

Collapsing actors' objectives into three categories presents two additional difficulties: first, actual identification of the possible objectives an actor might pursue; second, criteria for assignment of objectives to the categories. With regard to the identification of objectives, Hazlewood, *et al.,* have prepared useful lists of United States and crisis initiator objectives in 100 international crises from 1956 to 1976.[6]

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[6]See Leo A. Hazlewood, *Executive Aids for Crisis Management,* Interim Technical Report 76-19 (Arlington: CACI, Inc.-Federal, April 1977).

Although a number of these objectives are vague and ambiguous, little can be done to diminish this ambiguity outside analysis of specific deterrence situations.

The second difficulty is the criteria used to assign objectives to the three categories. For comparisons between bundles representing victory (V) and defeat (D), there is little difficulty. In most deterrence situations, decision makers have some, though possibly vague, ideas of the goals they wish to achieve, again showing structural-goal uncertainty. This bundle constitutes V, while D can be conceived as the inverse of V; namely, not achieving any of the objectives in V. Comparisons involving V and the status quo (SQ) are more problematic. If a decision maker acts, he obtains V with PR(V), D with PR(D) = 1 - PR(V), and, under the earlier assumption, PR(SQ) = 0. The problem is twofold: If a decision maker acts, will SQ obtain in any case? If he does not act, will V obtain in any case? It is difficult to reduce this uncertainty as well, other than through the examination of specific deterrence situations suggested above.

Regardless of how many objectives a decision maker assigns to categories V, SQ and D, an important factor is weighing these three categories and constructing a preference ordering and attendant utility function for them. If a decision maker assigns more than one objective to a category, an attendant problem concerns weighing objectives within that category. We do not suggest that decision makers actually construct a utility function for categories. That concept is used principally for theoretical and illustrative purposes. In fact, for the analysis to apply, it is really not necessary for decision makers to construct such a function. It is, however, necessary to obtain information on decision maker preferences for and/or weighting of objectives. This is somewhat more realistic, as national security decision makers often attempt to construct rough preference orderings for objectives and actions.

In many real world situations, such construction is performed by examining, at least implicitly and often explicitly, the benefits and costs of various objectives. Such an examination often leads to selection of

objectives, assignment to categories, ordering of the categories, and weighting of objectives within each category.

Discussion of benefit-cost calculations is hampered by structural-goal uncertainty, and reduction of this uncertainty is again context dependent. An additional element of uncertainty results from the fact that benefits and costs can be either tangible or intangible, e.g., prestige. It is, however, possible to develop useful lists of factors relevant to these calculations. An organizational basis for such lists has been developed in a report by Andriole, with more exhaustive lists of relevant factors resented therein.[7] Different sets of benefits and costs are relevant to different sets of objectives, and a more detailed examination again depends upon the specific deterrence situation.

A third, but relatively minor, problem arises regarding the abstract nature of the process through which decision makers construct their utility functions and, more fundamentally, select an actual course of action. The approach in earlier sections parallels that of other analysts who trace their theoretical heritage to the work of Von Neumann and Morgenstern.[8]

The construction of utility functions rests on a set of axioms about individual preferences and behavior, and the present analysis has been adapted from other work that rests on these axioms. The Von Neumann-Morgenstern approach has been labeled cardinal utility to distinguish it from a more recent approach, labeled lexicographic utility, which rests on a rather

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[7]See Steven J. Andriole, *Progress Report on the Development of an Integrated Crisis Warning System,* Technical Report 76-19 (McLean: Decisions and Designs, Inc., December 1976).

[8]Von Neumann and Morgenstern, *The Theory of Games and Economic Behavior,* (New York: John Wiley & Sons, 1954).

different set of axioms about individual preferences and behavior.[9] However, as it is more relevant to the actual selection of an action and the existence of decision maker's normalized utility functions are not crucial to empirical applications, we postpone consideration of the lexicographic approach to actual decisions to a subsequent part of this report.

4.3 Attitudes Toward Risk

Identification of factors relevant to decision makers' attitudes toward risk, while one of the most important, is perhaps one of the most difficult parts of the analysis. It is, however, possible to specify the major factors relevant to these attitudes and to changes in such attitudes, although the actual assessment of specific sets of decision makers in a deterrence situation necessitates examination of data that may have to be specially gathered for that purpose.

The most important factor relevant to the attitudes of decision makers is, of course, their psychological composition. This can likely be deduced from examination of biographical data, current psychological profiles and, most important, given the same set of decision makers, their past behavior in similar deterrence situations.[10]

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[9] Peter C. Fishburn, "A Study of Lexicographic Expected Utility," *Management Science,* 17, 11 (July 1971), pp. 672-678; Peter C. Fishburn, *Utility Theory for Decision Making* (New York: John Wiley and Sons, 1970); P. K. Pattanaik, "Group Choice with Lexicographic Individual Orderings," *Behavioral Science,* 18 (1973), pp. 118-123; Michael Taylor, "The Problem of Salience in the Theory of Collective Decision-Making," *Behavioral Science,* 15 (1970), pp. 415-430; Peter A. Wissel, "Foreign Policy Decision-Making: An Analytic Approach to Collective Decisions Without Voting," Ph.D. dissertation (Rochester: University of Rochester, 1973). A variation on the lexicographic approach is found in multi-attribute utility theory with differing weights for relevant attributes.

[10] See, for example, Irving L. Janis, *Victims of Groupthink: A Psychological Study of Foreigh-Policy Decisions and Fiascoes* (Boston: Houghton Mifflin Co., 1972) and Joseph H. De Rivera, *The Psychological Dimensions of Foreign Policy* (Columbus: Charles E. Merrill, 1968).

Since World War II, for example, both American and Soviet decision makers have displayed a marked propensity to accept risks in crisis situations. Thus, it is possible to reach the preliminary conclusion that both sets are generally risk acceptant in a wide variety of crisis situations. On the other hand, both sets have shown a marked aversion to potential escalation of crises, especially to the level of nuclear war. After the outbreak of the Korean War, American, Chinese, and Soviet decision makers were careful to consider the potential escalatory consequences of possible courses of action and imposed appropriate constraints upon themselves, making it possible to conclude that these sets are risk averse concerning decisions that entail a significant probability of escalation to strategic war.[11]

A second important factor related to the type of decisions produced by decision makers is the actual number involved. Contrasting styles appear in various contexts. In the United States, for example, one individual, the President, after receiving input from a variety of groups, is charged with the executive responsibility of making major defense and foreign policy decisions. On the other hand, in the Soviet Union, committees

[11]On the relationship between personality and deterrence, see Martin J. Bailey, "Deterrence, Assured Destruction, and Defense," *Orbis,* 16(1972), pp. 682-695. On the relationship between escalation and deterrence, see J. H. Polk, "The Realities of Tactical Nuclear Warfare," *Orbis,* 17(1973), pp. 439-447; D. N. Schwartz, "The Role of Deterrence in NATO Defense Strategy: Implications for Doctrine and Posture," *World Politics,* 28(1975), pp. 118-133. For a discussion of the official Soviet view of nuclear deterrence, see F. H. Garceau, "Nuclear Deterrence: The Soviet Position," *Orbis,* 8(1965), pp. 922-936.

of individuals are directly involved in the final decisions.[12] Again, the impact of this factor can only be assessed in examination of specific past, and possible future deterrence situations.

A last factor of relevance to decisions is only relevant if two or more decision makers are directly involved in the ultimate decision process -- namely, the actual process of decision used. Agenda development and group decision rules can have a significant impact on final decisions independent of the preferences of the individuals that compose the group. The net impact of this factor can only be determined by a fairly detailed knowledge of the actual rules a decision making body follows in developing its agenda and selecting an alternative from each. Although the theory dealing with this topic is well developed, real world applications have yet to be thoroughly explored.[13]

4.4 Probability Estimation

Factors relating to the decision maker's probability estimation, especially PR(V) and R(L), present some difficulty for the analysis. Logically, it is necessary to deal with more types of uncertainty than previously -- including relational-executional, relational-goal, structural-environmental and relational-environmental. Empirically, while it is

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[12] For a summary discussion of the relevant literature on group theory and its relevance to Soviet strategic decision making, see Paul Y. Hammond, Charles R. Plott and Abraham R. Wagner, *Social Choice and Soviet Strategic Decision-Making: The Influence of Group Processes on Policy and the National Command Authority (U)* (Marina del Rey, California: Analytical Assessments Corporation, May 1977) (SECRET). See also David A. Seaver, *Assessment of Group Preferences and Group Uncertainty for Decision Making*, Social Science Research Institute Technical Report 76-4 (Los Angeles: University of Southern California, June 1976).

[13] For a discussion of the theory relevant to agenda and group decisions, see Charles R. Plott, "Axiomatic Social Choice Theory: An Overview and Interpretation," *American Journal of Political Science,* 20(1976). See also Steven J. Brams, *Paradoxes in Politics* (New York: Free Press, 1975).

relatively easy to identify factors relevant to probability estimates, such as the quality and quantity of an actor's weapons systems, two difficulties are present:

- o   determining the number of relevant factors; and
- o   once the relevant factors are identified, assessment of their net impact on decision makers' probability estimates.

A number of authors have listed a large set of general and specific factors as being relevant to deterrence calculations.[14] Lengthy discussion of these authors' works is not particularly helpful in this relatively short report. However, the approach can be illustrated by examination of one aspect of a potential aggressor's probability estimation process: his calculations of the probability of a successful first strike on a defender's ICBM force.[15]

In approaching this planning, a potential aggressor faces one fundamental, indisputable problem; namely, the uncertainty involved, no matter how precise his mathematical calculations, in estimating the probability of a successful first strike. In this context, Steinbruner and Garwin note:

> Believing that well established assumptions which
> determine major policy judgments cannot be shaken

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[14] For example, see Martin J. Bailey, "Deterrence Assured Destruction, and Defense;" Donald G. Brennan, "The Case for Missile Defense," *Foreign Affairs*, 47(1969), 3(April), pp. 433-448; Colin S. Gray, "Foreign Policy and the Strategic Balance," *Orbis*, 18(1974), pp. 706-727; Benjamin S. Lambeth, "Deterrence in the MIRV Era," *World Politics*, 24(January 1972), pp. 221-242; Michael M. May, "Some Advantages of a Counterforce Deterrence," *Orbis*, 14(1970), pp. 271-283; George W. Rathjens, "Flexible Response Options," *Orbis*, 18(1974), pp. 677-688; John D. Steinbruner and T. M. Garwin, "Strategic Vulnerability: The Balance Between Prudence and Paranoia," *International Security*, 1(1976), 1(Summer), pp. 138-181.

[15] Some very specific calculations on just such an attack have been performed in an excellent study by Steinbruner and Garwin, "Strategic Vulnerability: The Balance Between Prudence and Paranoia."

> by a few bold strokes of the pen, we pursue in the
> discussion which follows some intricate details of
> the vulnerability problem. We do so in pursuit of
> broad purposes, however, which can be summarized by
> a few propositions: notably, that the beginning of
> wisdom on this issue is to be found in realization
> of the inevitability of ignorance and in acceptance
> of its consequences; *that on the basis of technical*
> *information available--at whatever level of privileged*
> *access--calculations of vulnerability are indeter-*
> *minate; that categorical assertions about vulnera-*
> *bility, which are frequently found in current*
> *political discourse, rest upon tacit assumptions*
> *more than technical fact; and, that the usual assump-*
> *tions are not the only ones which ought to be made*
> [italics added]. More succintly stated, vulnera-
> bility of the land-based missile forces...is far
> more a state of mind than a physical condition; but,
> nevertheless, it is an extremely important state of
> mind, worthy of the most exacting analysis.[16]

Steinbruner and Garwin identify a number of factors of immediate
relevance to the probability of success of a Soviet first strike on the
United States ICBM force. They note that defining a "successful" first
strike is a major difficulty, but posit 90 percent plus destruction of the
United States land-based missile force as a reasonable figure. They then
describe the net impact of a number of technical factors related to the
probability of a successful Soviet attack.

They note that neither the Soviet nor U.S. nuclear forces have actu-
ally been tested under battle conditions and this fact constitutes a basic
uncertainty attendant upon pre-attack planning; that is, Will the weapons
work as they are designed to work?

> ...calculations about overall force performance under
> actual combat conditions must be projected from data
> on single components under highly unrepresentative
> test conditions. What must be projected, moreover,

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[16] *Ibid.*, p. 140.

> is the overall technical performance of a missile
> force *the first time it is used*—not the performance
> which might result after many iterations. It seems
> obvious and compelling that *technical estimates gen-*
> *erated by such means must be treated as extremely*
> *uncertain and must be bounded by appropriately wide*
> *confidence intervals* [italics added].[17]

Thus, on this basis, we can rule out probability estimates as specific
numbers and concentrate attention on the net impact of technical factors
on the degree of uncertainty about the probability of a successful first
strike, that is, the size of interval [a;b].

With varying assumptions about the net impact of each of these fac-
tors and variations in Soviet attack strategy, Steinbruner and Garwin esti-
mate through computer simulation that a Soviet first strike with the cur-
rent Soviet missile force and, under the Vladivostok accords, its allowable
growth in the foreseeable future, would leave the United States with any-
where from 77 to 860 residual ICBMs.[18]

> Massive uncertainty...is not a stable condition of
> a decision-maker's mind. As a practical matter the
> simple, unrealistic but well-established calculations
> of the strategic balance have provided a clear struc-
> ture for the many decisions on strategic force posture
> which modern governments have had to make. Similarly,
> perceptions of threat throughout the world and politi-
> cal judgments which derive from such perceptions
> have been and undoubtedly will continue to be influ-
> enced at least in professional circles by the results
> of highly imperfect analytic calculations. Men cannot
> and do not shrink from the implications of strategic
> analysis even if scientific inference cannot carry
> them to firm conclusions.[19]

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[17]*Ibid.*, p. 141.

[18]*Ibid.*, pp. 171-174.

[19]*Ibid.*, p. 169.

Thus, in one relatively limited situation, and assuming away some relevant forms of uncertainty, probability estimation in a potential aggressor's pre-attack planning poses such massive difficulties and uncertainties that it is quite unrealistic to suggest that decision makers can, as a practical matter, arrive at specific probability estimates. Implicitly R(L) type *estimates can actually be made with fairly wide intervals* [a;b]. The import of these comments is reinforced if other aspects of pre-attack planning are included, such as the "mix" of a defender's weapons systems that would have to be targeted and the likely multiplicative effects of these aspects.

Finally, another compounding factor is the tendency of decision makers, especially in laboratory situations, *to misestimate the probability of various outcomes before an event occurs.*[20] However, the same factors encouraging rational behavior by national security decision makers operate here and would tend to reduce the magnitude of, but certainly not eliminate, such misestimates. Nevertheless, if the biases and misestimates tend to remain constant over time, we can still say something about decision makers changing estimates in response to changing factors.

4.5 Selection of an Action

Discussion of decision makers' actual selection of a course of action presents us with two major difficulties. Aside from doing nothing, most

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[20]See, for example, Baruch Fischhoff, *The Perceived Informativeness of Factual Information,* Technical Report DDI-1 (Eugene, Oregon: Oregon Research Institute, August 1976); Sarah Lichtenstein and Baruch Fischhoff, *The Effect of Knowledge on the Calibration of Probability Assessments,* Technical Report DDI-4 (Eugene, Oregon: Oregon Research Institute, August 1976); Sarah Lichtenstein, Baruch Fischhoff and Lawrence D. Phillips, *Calibration of Probabilities: The State of the Art,* Technical Report DDI-3 (Eugene, Oregon: Oregon Research Institute, August 1976); Paul Slovic, Baruch Fischhoff and Sarah Lichtenstein, *The Certainty Illusion,* Technical Report DDI-2 (Eugene, Oregon: Oregon Research Institute, August 1976).

deterrence situations present decision makers involved with a number of potential courses of action. Assuming that the major possible courses of action have been identified, the decision makers must attempt to deal with relational-executional uncertainty in eliminating all possibilities save one.

The previous assumption that a potential aggressor has two courses of action open to him is not as gross a distortion of reality as it initially might seem. In general, a decision maker can do nothing or take some action. As in the discussion of objectives, it is possible to regard any course of action as a bundle of reasonably well coordinated actions which is evaluated against the status quo alternative. This does not necessarily, however, have to be the case. It appears that in many real world deterrence situations, actions are often considered singly against the status quo, in pairwise comparisons, or each action is considered on its own against some abstract set of criteria that it must satisfy or be rejected without further deliberations.[21]

Implicit in all these logical and empirical analyses are the fundamental aspects of rational decision making; namely, that decision makers

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[21]See Barrett, et al., *Information Processing Types and Simulated Processing Types and Simulated Production Decision Making;* Judith Selvidge, *Methodology for the Retrospective Evaluation of Decision Analysis,* Technical Report, 76-13 (McLean, Virginia: Decisions and Designs, Inc., September 1976); Judith Selvidge, *Rapid Screening of Decision Options;* Darves and Carrigan, *Applications of Linear Models to Problems of Preference and Prediction;* J. Robert Newman, *Differential Weighting in Multi-Attribute Utility Measurement;* J. Robert Newman, D. Seaver, and Ward Edwards, *Unit Versus Differential Weighting Schemes for Decision Making: A Method of Study and Some Preliminary Results,* Technical Report SSRI 76-5 (Los Angeles: Social Science Research Institute, University of Southern California, July 1976); O'Connor and Edwards, *On Using Scenarios in the Evaluation of Complex Alternatives;* Slovic, Fischhoff and Lictenstein, *Behavioral Decision Theory;* Peter A. Wissel, "A Lexicographic Approach to Foreign Policy Decision-Making," paper delivered at the September 1971 meeting of the American Political Science Association.

attempt to assess their objectives in a deterrence situation; rank those objectives based on the assessed benefits and costs of each; assess their possible courses of action by estimating the probabilities associated with each outcome given a course of action; and select an action based on the benefits and costs of each action which are, in fact, the sum total of benefits and costs associated with each objective discounted by the probability of obtaining an objective given some action. Thus, as long as decision makers conform roughly to the axioms of rational choice and other biases remain relatively constant, this model is as good as any in assessing changing trends in probable courses of action.[22]

Adopting the "bundle" approach to selection of action, wherein decision makers evaluate the status quo against initiation of a bundle of coordinated actions, United States "action" in the Cuban missile crisis involved the following closely coordinated actions:

o   Repositioning and deployment of land, sea, and air forces;

o   Threatened use of nuclear weapons;

o   Changed alert status of nuclear and non-nuclear forces;

o   Naval quarantine;

o   Stepped up surveillance and intelligence operations;

o   Diplomatic action and protesting at United Nations; and

o   Initiating steps to gain cooperation and participation of
     other nations.

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[22]For an example of an approach to actual decision making that parallels these comments and our later analysis of real world deterrence situations, see Selvidge, *Rapid Screening of Decision Options*. Assessing possible courses of action open to decision makers, Hazlewood, Hayes, McIloy, Fain, Davis provide useful, though not exhaustive, lists of U.S. and crisis initiator actions in past deterrence situations.

This bundle was a response to a previously implemented Soviet bundle which included:

o   Repositioning and deployment of nuclear and non-nuclear forces;

o   Military assistance to Castro's forces;

o   Formalization of political, economic, and military commitment to survival of Castro's regime; and

o   Tacit support of Castro's efforts to spread his revolution to other Latin American countries.

As before, application of the factors discussed in this section must await examination of specific deterrence situations. We now turn to further consideration of our own computer aid: how it can assist in the analysis of the stability of a deterrence situation; how it can serve as one indicator of the possible emergence of a crisis situation resulting from the weakening of deterrence; its application to past, present, and future deterrence situations; and how it can aid the development of policies aimed at strengthening deterrence.

V. PROGRAMMING THE MODEL

A computer program has been developed to implement the dynamic crisis model considered above, along with a view toward assisting decision makers on a real time basis. This program is designed to provide an instantaneous printout listing the present values of the crucial variables in the decision maker's calculus as developed in Section 3.2, a graphical display of the trends in these values over time, as well as a numerical values expressing the gravity of the situation.

While the ideal empirical analysis would be one which would assign meaningful values for every variable in the calculus, it is clear that any attempt to do so at this stage of development would be unwise. Although it is theoretically possible to assign meaningful values for a decision maker's probability estimates, it is not necessarily true with respect to a decision maker's utilities for the various possible outcomes.[1]

Any attempt to do so would ignore the fact that there will exist infinite sets of utility numbers that will be consistent with every preference ordering. For a given probability estimate of the other party initiating an attack, some of these estimates will yield $EU(\cdot_2) > EU(\cdot_1)$, while others will yield $EU(\cdot_1) > EU(\cdot_2)$. Thus, we have chosen to focus on the probabilities each party estimates of the other attacking either from a desire for aggrandizement or fear and the judgment of experts as to the "true" probabilities in developing early warning capabilities.

5.1 Input

For any pair of nations whose relationship we wish to monitor, there are seven critical pieces of information that serve as input to the

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[1]See, for example, Central Intelligence Agency, *Handbook of Bayesian Analysis for Intelligence,* OPR-506, June 1975.

computer program. First, there is that nation's estimate, determined weekly, that the other prefers to initiate a first strike. That is, $\beta_{21} P \beta_{11}$ given an analysis of the situation from A's point of view. Second, there is that nation's estimate that the other may attack purely out of fear. Again, this probability is to be determined on a weekly basis. Thus, the probability assigned by a nation to the likelihood of an attack assumes that there is some general probability assessment which is shared by all of the relevant decision makers of that nation.[2]

The third data input is the probability, as determined by a panel of experts, that the nation in question is going to be the victim of an attack, for whatever reason. Each of these inputs will be stored for twelve weeks for use in providing a picture of the trends in the values of the variables.

The fourth data input is the preferences of the members of each National Command Authority concerning the choice between attacking and not attacking. These preferences are the preferences in effect *after* consideration of the likelihood of an opponent's attack.[3]

Fifth, there is the predicted collective decision of the National Command Authority. This last item can be either an input or an output, depending on our ability to axiomatize that nation's decision process.[4]

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[2] See David A. Seaver, *Assessment of Group Preferences and Group Uncertainty for Decision Making,* Technical Report 76-4 (Los Angeles: University of Southern California Social Science Research Institute, June 1976).

[3] The assumption of common probability estimates among NCA members is not inconsistent with differing preferences concerning the decision to attack or not; as mentioned above, differing utilities for the outcomes are sufficient to produce such a result.

[4] Little work has been done in trying to model the NCA decision process of any nation. However, recent work suggests this approach may be quite fruitful. Once a process is axiomatized, a computer can be programmed to determine the decision that will result given any set of members' preferences. See Paul Y. Hammond, Charles R. Plott, and Abraham R. Wagner, *Social Choice and Soviet Strategic Decision Making: The Influence of Group Processes on Policy and the National Command Authority (U)* (Marina del Rey, California: Analytical Assessments Corporation, May 1977) (Secret).

The sixth and seventh pieces of information that serve as inputs are the critical values of the total probability of being attacked and of the differential between the present and immediate past value of the total probability of being attacked.[5] The critical value of the total probability of attack is, as defined earlier, that value such that when the total probability of being attacked is greater than that critical value, the expected utility of a preemptive strike exceeds the expected utility of not attacking. The critical value of the differential between the present and immediate past values of the total probability of being attacked is that value which when reached signifies a developing crisis situation.

5.2 Data Sources

At least two alternative sources of information exist for the data that must be obtained for computer implementation of the model. One alternative is content analysis.[6] Content analysis involves examining the statements of national leaders to determine their preferences and probability estimates of action events occurring. Numerical scores can be attached to the frequency of occurrence of various statements and key words, and the probability estimates and preferences thus derived. The scanning of the leaders' statements can be done by man or machine.

A second approach, which has been used successfully in a number of analyses, involves the use of panels of experts.[7] The present analysis has previously stipulated that a panel of experts will be used to estimate the "true" probabilities of attack. Such panels can also

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[5] The total probability of being attacked, it will be recalled, is simply the sum of the probabilities of being attacked from fear and out of self-interest (the probability $\cdot_{21} > \cdot_{11}$) minus the product of those probabilities.

[6] Robert C. North, Ole R. Holsti, M. George Zaninovich, and Dina A Zinneg, *Content Analysis: A Handbook with Applications for the Study of International Crises* (Evanston, Illinois: Northwestern University Press, 1963).

[7] See Central Intelligence Agency, *Handbook of Bayesian Analysis for Intelligence*.

be used to determine values for all the other data inputs. Thus, panels of experts would be asked to estimate a nation's consensus probability estimate that the other party will attack, the preferences of the members of the National Command Authority, and the likely outcome of the decision process.[8]

It is this second approach which is recommended. It is envisioned that each nation would have its own panel of experts to assess the probabilities and preferences relevant to the program. Further, it would probably be a wise precaution to separate panels for the determination of true probabilities and the leaders' probability estimates.

5.3 Output Interpretation and Use

The printout obtained from the main routine of the computer program is shown for a hypothetical case in Figure 5.1. "Conflict Dyad AB" tells us that the information that follows involves Nations A and B. In each nation the program produces a printout of the probability estimates entered, followed by a graphical display of the trend in those estimates over the last twelve weeks. Additionally, each party's estimate of the "Total Probability of Being Attacked" is given, along with a graphical display of the trend of those estimates. Should these values pass the critical level, that fact is noted below. The final entries in each column are the preferences of the nation's NCA members and their predicted collective decision.

Following this, in the center of the page, each party's estimate of the "Total Probability of Being Attacked" is repeated, with the notation CRITICAL adjacent to any value above the critical level. Next, the

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[8]It might be noted here as evidence of the validity of this approach that in 1937, Frank Klingberg analyzed responses from 220 persons judged to be knowledgeable about world affairs. They were asked to estimate the probability of war within ten years for 88 pairs of states. The results, as reported on pp. 338-340 of Quincy Wright's *A Study of War* (Chicago: University of Chicago Press, 1964), were highly correlated with the orientation and sequence of entry of states in World War II.

FIGURE 5.1

CONFLICT DYAD AB

NATION A

A's PRESENT ESTIMATE THAT β_{21} P β_{11}: .35
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

A's PRESENT ESTIMATE OF AN ATTACK FROM FEAR: .10
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

A's PRESENT ESTIMATE OF TOTAL PROBABILITY
OF BEING ATTACKED: .42
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

EXPERTS' PRESENT ESTIMATE OF ATTACK BY B: .25
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

NATION B

B's PRESENT ESTIMATE THAT α_{21} P α_{11}: .40
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

B's PRESENT ESTIMATE OF AN ATTACK FROM FEAR: .15
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

B's PRESENT ESTIMATE OF THE TOTAL PROBABILITY
OF BEING ATTACKED: .49
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

EXPERTS' PRESENT ESTIMATE OF ATTACK BY A: .25
12-WEEK TREND:


```
1  2  3  4  5  6  7  8  9  10  11  12
```

FIGURE 5.1 (Con't.)

CONFLICT DYAD AB

NATION A

NATION B

PREFERENCES OF NCA MEMBERS:

X: $\alpha_{11} \; P \; \alpha_{21}$

Y: $\alpha_{21} \; P \; \alpha_{11}$

Z: $\alpha_{11} \; P \; \alpha_{21}$

W: $\alpha_{11} \; P \; \alpha_{21}$

PREDICTED DECISION: α_{11}

PREFERENCES OF NCA MEMBERS:

U: $\beta_{11} \; P \; \beta_{21}$

V: $\beta_{21} \; P \; \beta_{11}$

Q: $\beta_{21} \; P \; \beta_{11}$

PREDICTED DECISION: β_{21}

TOTAL PROBABILITIES OF BEING ATTACKED:

A: .42 [CRITICAL]
B: .49 [CRITICAL]

DIFFERENCE BETWEEN NCA's VIEW OF THE PROBABILITY OF BEING ATTACKED AND EXPERTS' VIEWS:

A: .19
B: .24

DIFFERENTIAL BETWEEN PRESENT AND IMMEDIATE PAST VALUE OF THE TOTAL PROBABILITY OF BEING ATTACKED:

A: .16 [CRITICAL]
B: .17 [CRITICAL]

WARNING CONDITION: 1

CRITICAL VALUES OF TOTAL PROBABILITY OF BEING ATTACKED:

A: .17
B: .22

DIFFERENCES:

A: .25
B: .27

CRITICAL VALUES OF DIFFERENTIAL BETWEEN PRESENT AND IMMEDIATE PAST VALUE OF THE TOTAL PROBABILITY OF BEING ATTACKED:

A: .10
B: .10

DIFFERENCES:

A: .06
B: .07

"Difference Between the Expert's Estimate and NCA's Estimate of Attack" is given. This is followed by the "Differential Between Present and Immediate Past Value of the Total Probability of Being Attacked." If this difference is past the critical value, it is so indicated.

The final aspect of the output for the main routine is the Warning Condition. There are six Warning Conditions, as follows:

o   Condition 1 indicates that the predicted decision of both NCAs is to attack.

o   Condition 2 indicates that the predicted decision of one NCA is to attack.

o   Condition 3 is signaled when the values of both nations' estimates of the "Total Probability of Being Attacked" have passed their respective critical values.

o   Condition 4 indicates one nation's estimate has passed the critical level.

o   Condition 5 indicates that the difference between the present and immediate past values of the "Total Probability of Being Attacked" has passed the critical level.

o   Condition 6 indicates none of the above events occurs.

These Warning Conditions are intended to give an approximation of the degree of seriousness of the situation. The higher the Warning Condition (i.e., lower the number), the greater the effort and the less the time available to prevent an outbreak of violence.

It is not feasible to separate every possible combination of circumstances into individual Warning Conditions without having an unduly large number of conditions. But we can and do provide a set of conditions which

place every situation into one, and only one, category.[9] Conditions 1 and
2 are considered most serious because they represent predicted decisions
to attack. Next most serious are Conditions 3 and 4 which are indications
that one or both sides' perceptions of the "Total Probability of Being
Attacked" have passed the level that requires serious consideration of a
preemptive attack. Least serious is the situation when only the differ-
ence between the present and past value of the "Total Probability of Being
Attacked" has passed some critical value.

While the program does not presently incorporate our "Difference
Between the Expert's Estimate and NCA's Estimate of Being Attacked" in the
determination of the Warning Conditions, its listing nevertheless plays an
important role. In one type of situation one or both nations may be in-
tending to go to war on the basis of the *false* impression that the other
side is likely to attack.

The existence of a false impression would be indicated by a large
positive differential. On the other hand, in some situations a nation's
estimate of a high probability of being attacked is in accord with the
expert's judgments. The value of knowing which is the case lies in the
guidance this knowledge gives to both intelligence and policy officials.
Large differences between experts' and policy makers' estimates should
call for rechecking intelligence information. If the rechecking verifies
the experts' estimates, then policy makers can embark on the appropriate
course of action; to convince the nations of their unreasonably high
estimates in one case, or warn the probable attackers and prepare to aid
the victims of an attack in the other.

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[9]When *two situations exist simultaneously*, the Warning Condition given
is the highest one associated with those conditions. Thus, if the predicted
decision of one nation is $._{21} P ._{11}$ and the difference between present and
past values of the Total Probability variable is past the critical level,
then Warning Condition 2 is indicated. Of course, the analyst will be
aware of lower level indicators due to their being included in the printout
above the Warning Condition. Hence, he can take them into consideration
in making recommendations.

Since it may be desirable for the analyst to have such information concerning the preselected critical levels and the difference between the actual and critical values, this information is made available in a sub-routine.

VI. AN ILLUSTRATION

In this chapter an attempt is made to illustrate how the computer program described above could have been used in a specific historical situation, namely the interaction between Eqypt and Israel during the three-week period prior to the outbreak of the 1967 Six Day War. The specific events of this crisis period have been documented in numerous publications.[1] Thus, the information necessary to make judgments as to probabilities and preferences of the principal actors is readily available.

It is not suggested that the probabilities or individual preferences are identical with those that would have been estimated during the actual crisis or even now, given additional time for analysis and contemplation. They are rough approximations whose main function is to illustrate the potential application of the computer program developed.

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[1]See, for example, Randolph S. Churchill and Winston S. Churchill, *The Six Day War* (London: Heinemann, 1967); Walter Laqueur, *The Road to War: The Origins and Aftermath of the Arab-Israeli Conflict 1967-68* (Baltimore, Maryland: Penguin, 1970); Walter Laqueur, ed., *The Israeli-Arab Reader: A Documentary History of the Middle East Conflict* (2nd ed.; New York: Citadel Books, 1970); Abraham R. Wagner, *Crisis Decision Making: Israel's Experience in 1967 and 1973* (New York: Praeger, 1974); Michael Howard and Robert Hunter, "Israel and the Arab World: The Crisis of 1967," *Adelphi Papers,* No. 41 (London: Institute for Strategic Studies, 1967); Nadav Safran, *From War to War: The Arab-Israeli Confrontation 1948-1967* (New York: Pegasus Books, 1969); Theodore Draper, *Israel and World Politics: Roots of the Third Arab-Israeli War* (New York: Viking Press, 1967); Michael Bar-Zohar, *Embassies in Crisis: Diplomats and Demagogues Behind the Six Day War* (Englewood Cliffs, N.J.: Prentice-Hall, 1970); Winston Burdett, *Encounter with the Middle East* (New York: Atheneum, 1969); Shmuel Segev, *Sadin Adom* (Red Sheet) (Tel-Aviv: Tversky, 1967); Shlomo Nakdimon, *Likrat Sha'at Ha'efes: Ha'drama She'hadama L'milhemet Sheset Ha'yamin* (Towards the Zero Hour: The Drama that Preceded the Six Day War) (Tel-Aviv: Ramdor, 1968); Eric Roulau, Jean Francis Held, and Jean Lacouture, *Israel et les Arabes, le 3^e Combat* (Paris: Editions du Seuil, 1967); and Michael Brecher, *Decisions in Israel's Foreign Policy* (Oxford: Oxford University Press, 1975).

The remainder of this chapter is divided into five sections. For Section 6.1, the respective NCA's of Egypt and Israel are enumerated. The next three sections deal with the three weeks preceding the Israeli attack of 5 June 1967. In each section a display of hypothetical probability and preference data is given. The final section summarizes the possible uses to which the information could be put.

6.1 Egyptian and Israeli National Command Authorities - 1967

As illustrated in Table 6.1, the Egyptian National Command Authority for the entire 1967 pre-war period can be considered to consist of two individuals: President Gamal Abdul Nasser and War Minister Shamis al-Din Badrin. While certainly not an absolute dictator, Nasser's public support in Egypt and the whole Arab world gave him enormous power in determining policy positions for Egypt. Only his War Minister's assent or acquiesence was really necessary for him to launch an attack.[2]

As might be expected, the Israeli National Command Authority was more complex. In the pre-war period, membership in the Israeli NCA was not equivalent to Cabinet membership or even membership in the Ministerial Committee on Security and Defense (MCSD).[3] It was, rather, a subset of the latter, and varied between the inception of the crisis and the outbreak of the 1967 war.

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[2]To precisely distinguish their relative power concerning war/peace decisions, we would suggest that Nasser's preference for war was one necessary condition for an Egyptian attack, while Badrin's preference or indifference was the other.

[3]The term NCA is not used to suggest that an Egyptian or Israeli National Command Authority formally existed, or that in the Israeli case national security decisions were taken at meetings consisting only of NCA members. Rather, membership in the NCA connotes significant influence in the collective choice of action.

TABLE 6.1

MEMBERS OF ISRAELI AND EGYPTIAN NATIONAL COMMAND AUTHORITIES

	ISRAEL	EGYPT
FRIDAY **19 May 1967**	Levi Eshkol	Gamal Abdul Nasser
	Yigal Allon	Shamis al-Din Badrin
	Abba Eban	
	Israel Galili	
	Pinhas Sapir	
FRIDAY **26 May 1967**	Levi Eshkol	Gamal Abdul Nasser
	Yigal Allon	Shamis al-Din Badrin
	Abba Eban	
	Israel Galili	
	Pinhas Sapir	
FRIDAY **2 June 1967**	Levi Eshkol	Gamal Abdul Nasser
	Moshe Dayan	Shamis al-Din Badrin
	Yigal Allon	
	Abba Eban	
	Israel Galili	
	Pinhas Sapir	

Up until 1 June 1967, the Israeli NCA could be said to consist of
five individuals. First, there was Levi Eshkol, the Prime Minister and
Minister of Defense. Whatever may be said about his allegedly hesitant
and equivocal leadership, he was the Prime Minister and thus bore ultimate
responsibility for any Israeli decision. Second was Abba Eban, Foreign
Minister, whose "incurable optimism" and consequent faith in diplomatic
solutions made him Israel's leading dove. Third was Yigal Allon, who
served as Labor Minister at the time and is also considered a member of
the 1967 Israeli NCA. His membership was due not to his Labor portofolio,
but rather to his distinguished military career and considerable political
influence. The final two members of the pre-June NCA are considered to be
Israel Galili, minister without portfolio, and Pinhas Sapir, Finance Minis-
ter and powerful political figure in the ruling Labor Party. Sapir, a
supporter of Abba Eban, was considered to be a dove, while Galili was one
of Israel's foremost hawks.

On 1 June 1967, several significant changes took place in the mem-
bership of the Israeli Cabinet. In an effort to form a government of
national unity, several leading members of opposition parties were incor-
porated into the Israeli Cabinet. Specifically, Menahem Begin and Joseph
Sapir of the *Gahal* Party were made ministers without portfolio, while
Ya'acov S. Shapiro and Eliahu Sasson of *Ma'arach* (Labor Alignment) were
made Ministers of Justice and Police, respectively. Most importantly,
Eshkol gave up the dual posts of Prime Minister and Defense Minister,
with Moshe Dayan taking over the Defense portfolio. This last change
was also reflected in NCA membership, as Dayan became the sixth NCA mem-
ber.

Table 6.1 lists the varying compositions of the Israeli NCA along
with the Egyptian NCA membership for the three Fridays preceding the Israeli
strike of 5 June 1967.

6.2 The Week Ending 19 May 1967

The week beginning 13 May 1967 and ending on 19 May 1967 marked the
beginning of the crisis that preceded the Six Day War. On 14 May, Egypt
sent military units through the streets of Cairo toward the Suez Canal

and Sinai. At 1430 Egyptian time, the alert status of Egyptian forces was raised to a "maximum alert" or "battle readiness" status. The news of this information reached Israeli Prime Minister Eshkol the following day, Israeli Independence Day. Eshkol's only reaction was to place forces on alert, although it was noted that the Israeli military parade in Jerusalem lacked any heavy armor or large numbers of troops, thus "adding to the speculation that they were deployed elsewhere."[4]

Throughout the next several days, Egyptian activities further heightened the prospect of war. On 16 May, Egyptian troops were seen crossing the Suez Canal and entering Sinai. That same day Egypt also requested the removal of UNEF troops from Sinai and declared a state of emergency. The following day, 17 May, Cairo Radio broadcast threats to remove UNEF by force so they "would not be harmed if hostilities broke out."[5] On 18 May, Cairo Radio repeated that Egyptian troops were on maximum alert. Additionally, UN compliance with the Egyptian demands resulted in Egyptian occupation of UNEF outposts in the Sinai.

Finally, on 19 May, Israel mobilized additional troops and increased antiaircraft security while 30,000 Egyptian troops were transferred from the civil war in Yemen to the Sinai. Additionally, reports reached Israeli leaders that Egyptian planes had violated Israeli airspace from Jordan.

Table 6.2 shows how the computer output might have looked on the morning of 20 May 1967.[6] Discussion of this sample output and figures is deferred until Section 6.5, which follows.

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[4]Wagner, *Crisis Decision Making*, p. 67.

[5]*Jerusalem Post*, 18 May 1967, p. 1.

[6]Since activities during the weeks preceding the initiation of the 1967 crisis are not particularly well documented, the trend lines which require estimates for twelve-week periods have been omitted.

TABLE 6.2

CONFLICT DYAD ISRAEL-EGYPT: WEEK ENDING 19 MAY 1967

CONFLICT DYAD ISRAEL   EGYPT   WEEK 10

	ISRAEL	EGYPT
PRESENT EST. THAT 21 P 11:	0.40	0.15
PRESENT EST. OF ATTACK FROM FEAR:	0.08	0.15
PRESENT EST. OF TOTAL PROB. OF BEING ATTACKED:	0.45	0.28
EXPERTS EST. OF ATTACK BY OTHER:	0.30	0.25

ISRAEL

NCA PREFERENCES

ESHKOL	STATUS QUO
ALLON	STATUS QUO
EBAN	STATUS QUO
GALILI	WAR
DAYAN	STATUS QUO
SAPIR	WAR

PREDICTED DECISION: STATUS QUO

EGYPT

NCA PREFERENCES

| NASSER | STATUS QUO |
| BADRAN | WAR |

PREDICTED DECISION: STATUS QUO

TOTAL PROBABILITIES OF BEING ATTACKED
ISRAEL   0.45 *** [CRITICAL]
EGYPT   0.20

DIFFERENCE BETWEEN NCA'S VIEW OF THE TOTAL
PROBABILITY OF BEING ATTACKED AND THE EXPERTS VIEW
ISRAEL   0.15
EGYPT   0.25

DIFFERENTIAL BETWEEN PRESENT AND IMMEDIATE
PAST VALUE OF THE TOTAL PROBABILITY OF BEING ATTACKED
ISRAEL   0.15 *** [CRITICAL]
EGYPT   0.05

WARNING CONDITION: 4

6.3 The Week Ending 26 May 1967

The second week of the 1967 crisis began with a spreading sense of alarm in Israel as a partial mobilization was completed. The following day, Egyptian forces completed their takeover of UNEF positions, and 30,000 troops were installed along the entire border from Gaza to Sharim al Sheik. In addition, the UAR ordered a "total mobilization" of its 100,000 reservists.[7]

May 22 and 23 were marked by significant statements by the respective national leaders. On 22 May, Eshkol noted that Egyptian forces in Sinai had been increased from 35,000 to 80,000, while Nasser announced that the Straits of Tiran were to be closed to Israeli shipping. Both goods carried on Israeli ships and ships of other nations bound for Eilat were barred.

Additional bellicose statements emanated from Jerusalem and Cairo on 23 May, with Prime Minister Eshkol declaring that any interference with shipping in the Gulf of Aqaba and the Sinai would be considered as acts of aggression against Israel. In a speech over Cairo Radio, Nasser asserted that there would be no passage of Israeli flag carriers through the Gulf of Aqaba and that "our armed forces and all our people are ready for war."[8]

Finally, in an address to the Arab Trade Union Congress on 26 May, Nasser indicated that his closing the Straits of Tiran was a deliberate attempt to produce a war.

Table 6.3 demonstrates how the computer output might have looked on the morning of 27 May 1967.

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[7]This "mobilization" has been considered largely a propaganda move. See Wagner, *Crisis Decision Making,* p. 71.

[8]Draper, *Israel and World Politics.*

TABLE 6.3

CONFLICT DYAD ISRAEL-EYGPT: WEEK ENDING 26 MAY 1967

CONFLICT DYAD ISRAEL   EGYPT   WEEK 11

	ISRAEL	EGYPT
PRESENT EST. THAT 21 P 11:	C.50	0.70
PRESENT EST. OF ATTACK FROM FEAR:	0.30	0.33
PRESENT EST. OF TOTAL PROB. OF BEING ATTACKED:	0.65	0.80
EXPERTS EST. OF ATTACK BY OTHER:	0.55	0.75

ISRAEL

NCA PREFERENCES

ESHKOL	WAR
ALLON	WAR
EBAN	STATUS QUO
GALILI	WAR.
DAYAN	STATUS QUO
SAPIR	WAR

PREDICTED DECISION: WAR
EGYPT

NCA PREFERENCES

NASSER	STATUS QUO
BADRAN	WAR

PREDICTED DECISION: WAR

TOTAL PROBABILITIES OF BEING ATTACKED
| ISRAEL | 0.65 | *** | [CRITICAL] |
| EGYPT | 0.80 | *** | [CRITICAL] |

DIFFERENCE BETWEEN NCA'S VIEW OF THE TOTAL
PROBABILITY OF BEING ATTACKED AND THE EXPERTS VIEW
ISRAEL   0.10
EGYPT .   0.05

DIFFERENTIAL BETWEEN PRESENT AND IMMEDIATE
PAST VALUE OF THE TOTAL PROBABILITY OF BEING ATTACKED
| ISRAEL | 0.20 | *** | [CRITICAL] |
| EGYPT | 0.60 | *** | [CRITICAL] |

WARNING CONDITION: 3

6.4 The Week Ending 2 June 1967

The week beginning on 27 May brought further statements by Egyptian leaders and spokesmen concerning the inevitability and necessity of war between Israel and the Arabs. On 28 May, Muhammad Haykal, a Nasser confidant and editor of Cairo's semi-official *al-Ahram* stated that war was inevitable, while Nasser said that Israel threatened war and that it would be welcomed. The following day (29 May) he stated Tiran was not the issue, but rather the very existence of Israel was.

As important as Nasser's speech, at least to the Israelis, was the article by Haykal. Haykal was clearly the most respected Arab journalist at the time, and the general feeling in Israel was that he more accurately represented what Nasser meant than what Nasser himself had said. His statement on the inevitability of war was not taken lightly. In addition to the verbal battle, a significant act on 30 May also occurred, in the signing of an Egyptian-Jordanian defense pact. Israel had long said such a move would serve as a *casus belli*.

While Nasser was throwing verbal brickbats at Israel, the Israeli political situation was in a state of flux. On 27 May, an Israeli Cabinet meeting decided in favor of peace.[9] At this time the opposition parties closed ranks on the government coalition and secured several major defections from it. As Ben-Gurion, Begin and their associates met in Tel-Aviv, the *Mapai* (Labor Party) agreed to co-opt the *Rafi* (a splinter faction), if not the opposition *Gahal* as well, into a National Unity Government. The major sticking point was the demand by the oppositionists that Moshe Dayan be given the Defense portfolio.

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[9]In actuality, it failed to decide on war. See Wagner, *Crisis Decision Making*, pp. 78-79.

In an effort to reach a compromise, Eshkol agreed to Cabinet posts for four additional members as ministers without portfolio: Golda Meir, Moshe Dayan, Menahem Begin, and Joseph Sapir. This was rejected by the oppositionists because it would leave Dayan without a major role. Eshkol addressed the nation and stressed a "continuation of political action" to open the Tiran Straits, rather than the necessity for military action. The exceedingly poor delivery of this speech by Eshkol, and the circumstances surrounding it, caused a marked decline in public confidence toward Eshkol, making it clear to the political leadership of the Labor Party that some compromise would have to be reached.

Negotiations continued over the next two days, with the proposed inclusion of Moshe Dayan in the Israeli Cabinet as Minister of Defense remaining as the major stumbling block. Finally, on 1 June 1967, at an afternoon meeting of the *Mapai* Central Committee, it was decided, over the objection of both Eshkol and Meir, that Dayan would be offered the Defense portfolio. Pro forma ratification occurred the next day (2 June) by the Ministerial Committee on Security and Defense. This appointment, along with the announcement of the formation of a National Unity Government, restored the morale of the Israeli public and gave the military a needed boost.

Israeli air strikes occurred the following Monday, and within six days the war was over. Table 6.4 shows how the computer output might have looked on the morning of 3 June, two days prior to the outbreak of the June 1967 war.

6.5 Summary Conclusions

Sections 6.2 through 6.4, above, present a brief overview of the crisis in the weeks leading up to the Israeli attack commencing the Six Day War. In the first period, Egypt combined verbal threats with troop movements and the request for UNEF withdrawal from the Sinai Peninsula. Meanwhile, the only Israeli reaction in that time period was to place its forces on alert.

TABLE 6.4

CONFLICT DYAD ISRAEL-EGYPT: WEEK ENDING 2 JUNE 1967

CONFLICT DYAD ISRAEL   EGYPT   WEEK 12

	ISRAEL	EGYPT
PRESENT EST. THAT 21 P 11:	0.50	1.00
PRESENT EST. OF ATTACK FROM FEAR:	0.50	0.20
PRESENT EST. OF TOTAL PROB. OF BEING ATTACKED:	0.75	1.00
EXPERTS EST. OF ATTACK BY OTHER:	0.60	0.90

ISRAEL

NCA PREFERENCES

ESHKOL	WAR
ALLON	WAR
EBAN	STATUS QUO
GALILI	WAR
DAYAN	STATUS QUO
SAPIR	WAR

PREDICTED DECISION: WAR

EGYPT

NCA PREFERENCES

NASSER	WAR
BADRAN	WAR

PREDICTED DECISION: WAR

TOTAL PROBABILITIES OF BEING ATTACKED
ISRAEL   0.75 *** [CRITICAL]
EGYPT   0.75 *** [CRITICAL]

DIFFERENCE BETWEEN NCA'S VIEW OF THE TOTAL
PROBABILITY OF BEING ATTACKED AND THE EXPERTS VIEW
ISRAEL   0.15
EGYPT   0.10

DIFFERENTIAL BETWEEN PRESENT AND IMMEDIATE
PAST VALUE OF THE TOTAL PROBABILITY OF BEING ATTACKED
ISRAEL   0.10 *** [CRITICAL]
EGYPT   0.20 *** [CRITICAL]

WARNING CONDITION: 1

The figures given in the output displayed in Table 6.2 attempt to reflect this atmosphere of crisis but not immediate war. The probability value assigned to Egypt's "Present Estimate of the Total Probability of Being Attacked" is based in all the tables on Nasser's own statements.[10] Assignment of preferences to the various NCA members is based on the numerous accounts of decision making during the crisis.

Using the framework established, an analyst would have noted that the Israeli perception of the Total Probability of Being Attacked had substantially passed the critical level. It would thus be advisable to monitor very closely possible Israeli preparations for a first strike.

The week ending 26 May 1967 brought an intensification of the crisis, with Nasser's closing the Straits of Tiran and announcing that Egypt was ready for war. Likewise, the Israeli decision to proceed with full mobilization and Eshkol's statement concerning the rights of Israeli shipping also heightened the war atmosphere. These events are captured by the new probability estimates in the output displayed in Table 6.3. Both Israeli and Egyptian perceptions of the probability of an attack have passed the critical level, and the expert's views have approached the views of the national decision makers. Additionally, the rate of change in the probability of being attacked has also passed the critical level. These results would indicate the need to both slow down the pace at which the crisis is developing and forestall a decision on the part of either NCA to attack.

The events of 27 May through 1 June 1967 made the occurrence of war an inevitability, or at least that seemed to be the case. In any case, the information displayed in the computer printout would have alerted analysts and policy makers to the need for immediate action, either to prevent conflict, if at all possible, or to prepare for it.

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[10] See Laqueur, *The Road to War*, p. 123.

VII. CONCLUSIONS AND POTENTIAL
APPLICATIONS IN CRISIS WARNING

A fundamental objective of the present research, as implemented in a preliminary fashion in the computer program and related graphic displays, has been to develop a dynamic analytical framework for a variety of crisis situations. In meeting this objective, a dynamic deterrence model was developed from a number of classical "static" concepts of deterrence, and a computer program subsequently developed from these results, implementing a formal model of crisis dynamics with practical applications.

Development of the formal model of crisis dynamics involved major revisions of the static classical model of deterrence, which assumes a potential aggressor and deterrer, both of whom are rational actors. In the model, the potential aggressor is faced with the strategic choice between the status quo situation, if he does not choose to attack, and a "lottery" option between victory and defeat in the event he chooses to attack rather than continue with the status quo situation. Whether the deterrer's threats will be successful in forestalling an attack will depend on at least four factors:

o   the potential aggressor's gains if he achieves his objectives in an attack;

o   the probability that such an aggressor achieves these objectives;

o   the potential losses from an unsuccessful attack; and

o   the attitude which a potential aggressor holds toward risk.

The dynamic crisis model revises the classical model in a number of important respects. Nations involved in the analysis are no longer dichotomized as a potential aggressor and deterrer. Rather, each nation is characterized as perceiving the other as a potential aggressor. Under these new assumptions the one-sided optimization problem becomes a game-theoretic problem. In the crisis model, each nation is uncertain of the collective preference of the other, unsure of whether a potential enemy prefers an attack initiated by him to the status quo. Even in cases where both sides prefer the status quo, one or both might initiate an attack if the probability that the other is planning an attack is reasonably high.

Recognition that this uncertainty exists in the mind of an opponent introduces an additional element into the decision calculus of each nation. These nations must now adjust their expectations of being attacked to include the probability that a potential opponent will attack to avoid being the victim of a preemptive first strike. Thus, each of the nations in the analysis must perceive some value for the probability that it will be attacked due to its opponent's desire for substantive gains, as well as the additional probability that it will be attacked due to a fear that it will itself attack preemptively.

7.1 Computer Implementation

The preliminary computer program and related graphics display developed in Chapter V, above, implement this dynamic model in an operational form.[1] While the program, in its current form, does not make expected utility calculations for either nation, the probability estimates and ordinal preferences of each nation involved play a central role in the computer model. Both the probability that a nation will be attacked for reasons of self-interest and the probability that it will be attacked out of fear of pre-emption are estimated for each National Command Authority (NCA).

Given these estimates, the preferences of each NCA member are then estimated along with the predicted collective decision. On the basis of this data, six warning conditions are defined indicating the likelihood of conflict and the time available to prevent it.

What remains is for the dynamic model, and the computer program implementing it, to be thoroughly tested in a variety of crisis situations and to be refined as a crisis management tool. Several steps in this direction can be suggested. First, a thorough examination of several past and foreseeable crisis situations can be examined within the framework of the model, utilizing the program. Second, it is possible to adapt the program so as to incorporate utilities leading to direct expected utility calculations.

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[1] A program listing can be obtained from the authors, or through the Cybernetics Technology Office, Defense Advanced Research Projects Agency.

A primary focus of any analysis of historical crisis situations should be on crises which have resulted in the outbreak of war, considering the events of each weekly period prior to the outbreak of hostilities for at least 12 weeks in advance of such an outbreak. Likewise, for more recent and current crisis situations which have the potential of leading to hostilities, it is suggested that expert panels be utilized to provide estimates of the critical variables involved. Looking at the results of the application in Chapter VI, above, it appears that an analysis of the 12- to 24-week period prior to most crisis situations would permit the analyst to address several important questions.

This set of questions revolves around the utility of the probability estimates in reflecting changes in the political situation; in the realism of the critical values selected; on the ability of the experts to separate their subjective opinions from their objective estimates of various national leadership judgments; and, on the likely uniformity in the estimates of such a panel.

Specifically, the important questions to be addressed include a consideration of:

o the variance within the various probability estimates from week to week during a crisis period, and whether such variations are likely to reflect significant changes in the political situation short of an obvious major crisis, or will they be of the step function variety;

o what are realistic critical values for the "Total Probability of Being Attacked" variables, and the "Critical" indication in the computer program, as well as what values of these variables have been associated with increased military and political preparations for hostilities;

o any tendency for the experts' estimates of the attack probabilities assigned by a nation's National Command Authority to coincide with individual subjective estimates;

o whether the choice of experts to serve on an estimating panel is likely to be crucial to the probability values and decisions estimated, and whether a different panel would produce significantly differing results;

o   whether there is a slow progression from lower to higher level
     conditions, or is there a sharp break from lower to higher
     level warning indications; and

o   are the estimates for each weekly period, in retrospect, accu-
     rately reflective of the actual situation at those points in
     time.

The questions raised above with regard to estimation by panels of experts
will not require a particularly large number of experts to resolve, and it is
estimated that a limited number of individuals can be asked for their estimates
with panels created by combining subsets of the full panel in alternative sub-
panel estimates. Utilizing such data, both intra- and inter-panel comparisons
can be achieved. Inter-panel comparisons would focus on the variance among
different panel estimates of the same variables, while intra-panel comparisons
would focus on determining whether experts' personal estimates coincide with
objective estimates derived for leaders in the National Command Authority.

7.2 Incorporation of Utilities Into the Model

In addition to the foregoing implications for further testing and pro-
gram development, it now appears feasible to at least attempt incorporation
of utilities explicitly into the model. Such a modification would involve:
determining an aggregate utility function over the National Command Auth-
ity in any given case for the various possible outcomes; calculating the ex-
pected utilities for each alternative course of action; and altering the warning
conditions indicated in the computer program accordingly.[2]

Of prime importance to the further implementation and programming of the
model is a determination of the sensitivity of the relationship between the
expected utility of attack and the expected utility of the "no attack" actions
to variations in the utility estimates. Within the theoretical framework

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[2]One effort at such aggregate utility calculations is contained in
Abraham R. Wagner, *Crisis Decision-Making: Israel's Experience in 1967 and
1973* (New York: Praeger, 1974). Also, see Abraham R. Wagner, "A Rational
Choice Model of Aggression: The Case of the Six Day War," in Patrick J. McGowan
(ed.), *International Yearbook of Foreign Policy Studies (Volume III)* (Beverly
Hills: Sage Publications, 1975).

established, and the program developed, it should be possible to determine
critical values for both utilities and probabilities, which make the proba-
bility of attack greater than the expected probability and associated utility
of not doing so.

7.3   Potential Areas of Application

Considered in Chapter VI above was one historical example of how the
model and related programming might have been used in one crisis situation.
What has been suggested for further development of the model, and its imple-
mentation as an executive aid to crisis management, is further testing on a
variety of historical and potential crisis situations. Considered below are
several possible areas where crises of major importance to the United States
could arise, and in which the tools developed might be of use. Particular
emphasis has been given to U.S. - Soviet interactions, although the applica-
bility to other conflicts remains as well.

While neither United States - Soviet, nor NATO - Warsaw Pact relations
can be said to be in a crisis phase presently, it is possible to utilize the
model developed in Chapter III to analyze the effects of changes in technology
or force balances on the payoffs that would exist should such a crisis situation
arise. Since the payoffs are intimately linked to the courses of action chosen,
the question becomes one of considerable importance. Developed below are several
aspects of the U.S. - Soviet and NATO - Warsaw Pact relationships on which the
analysis could focus.

(a)   United States - Soviet Strategic Nuclear Relationship:

In Chapter III, it was assumed that if a major strategic conflict was to
occur, each nation would prefer to be the initiator, at least from the stand-
point of perceived costs and losses. Failing this, the next most preferred
alternative was for such a conflict to begin with close to simultaneous ex-
changes. Least preferred, for any nation, is to be the victim of a full-scale
first strike attack.

While this assumption was probably correct with respect to United States
and Soviet attitudes toward nuclear war in the early 1960's, it was probably
no longer an accurate statement by the middle part of that decade. In the

early 1960's, the United States had an overwhelming advantage over the Soviets in terms of deliverable nuclear weapons, while the absolute numbers of Soviet weapons were relatively small and inter-continental delivery capabilities fairly limited. A first strike by the U.S. would have destroyed the major stock of Soviet weapons, preventing their subsequent use against CONUS. While the Soviet Union would have suffered large scale damage whether or not they were the initiators of a first strike, permitting them to launch such a strike would have inflicted large scale damage on the U.S. as well.

By the mid-1960's, the strategic situation had shifted dramatically. Both the U.S. and the Soviets had substantial numbers of missiles available in operational status. These missiles had, however, a rather low kill probability against opposing missile forces, which had by this time been located in hardened silos. Hardening at this time had been especially effective for the United States, and less so for the Soviets. Thus a Soviet counterforce first strike against the United States would have essentially exhausted the Soviet missile force but destroyed only a portion of existing U.S. missiles.

The subsequent result would have been a commanding U.S. strategic position. In this case the net payoff for striking first would have been lower than the payoff for being a "victim" of such an attack. A similar analysis would apply to a U.S. strike. Thus deterrence, even in a potential crisis situation, was stable.

With the advent of MIRV's and increasing accuracies of individual weapons, the payoffs may again be in accord with the assumptions of the model. One missile with three independently targetable warheads, for example, can be used against three missile sites. Coupled with improved accuracies, these changes sharply increase the probability of a successful first strike. Thus, at least in terms of land-based forces, the vulnerability that was removed with the introduction of hardened silo basing may be restored.

In evaluating possible changes in the United States and Soviet strategic capabilities, one factor that should be kept in mind is the net effect of such changes on crisis situation payoffs. At the present time, it is still uncertain whether or not the provisions of a proposed SALT-II agreement will serve to

stabilize deterrence in foreseeable crisis situations, and whether any unilateral improvements in the technology base by the United States will have a beneficial effect in such a crisis.

Also of importance to the analysis is the uncertainty produced by changes in the variables over time, which has been at the heart of the present analysis. As the payoff to one nation of striking first rises relative to the payoff of maintaining the status quo, the other nation is likely to perceive an increased probability of being the victim of an attack. This, in turn, increases the payoff from initiating such a first strike and the probability that such a nation will do so.

Specific areas that may affect crisis situation payoffs and perceptions of likely adversary choices in the context of the present strategic environment include the U.S. cruise missile, the number of "heavy" Soviet missiles, the mix of land and sea based missiles, the number of mobile missiles, advances in anti-submarine warfare, the development of hunter-killer satellites, and improvements in missile targeting accuracies.

All other things being equal, the more Soviet "heavy" missiles in that nation's stockpiles, the greater the payoff to the Soviets from a first strike relative to the payoff of maintaining the status quo. On the other hand, the effect of U.S. deployment of cruise missiles becomes more problematical from the viewpoint of the analysis. If the Soviets are unable to destroy a large enough portion of the U.S. strategic nuclear force to avoid massive retaliation, the introduction of cruise missiles would only produce a marginal decrease in the value of initiating a first strike, which will already by quite low.

If, due to increased Minuteman and SLBM vulnerability, cruise missiles are utilized as the main retaliatory weapon in a U.S. counter-force strike, they could be expected to sharply reduce the Soviet payoff from a first strike. Since they are relatively poor counter-force weapons, they will not increase significantly the payoff to the U.S. from a first strike. Therefore, they could be expected to have a stabilizing effect on crisis deterrence.

In the real world, however, all "other things" are rarely "equal," and therefore it is logical to expect that it will be necessary to evaluate the simultaneous effects of several changes, some of which may be only probabilistic.

Further, it is necessary at some point in the development of the model to assess the effects in the critical variables produced by responses to these changes over time.

(b) NATO - Warsaw Pact Confrontations:

The deterrence relationship between NATO and Warsaw Pact forces has been of major importance to strategic planners, and its stability second only to the direct Soviet - American strategic relationship. One aspect of this relationship of critical interest currently, and a potential candidate for the application of the analysis, is the impact on the deterrence relationship of the introduction of new weapons systems into the balance. Two possible candidates having a potentially large impact on this stability are the cruise missile and the neutron (enhanced radiation) bomb.

Operationally, cruise missiles currently programmed would allow NATO to penetrate Soviet and Pact air defenses in order to destroy intermediate range Soviet missiles and Pact aircraft targeted against Western Europe. In a conflict, it is entirely possible that Soviet IRBM's and nuclear weapons would not be utilized in the initial stages in the hope of keeping such a conflict at the conventional level. To the extent that NATO deterrence posture is based on nuclear retaliatory and defensive capabilities, calculations in the model could be dramatically altered.

Similarly, the neutron or enhanced radiation bomb could be utilized by NATO to neutralize the Warsaw Pact's superior armed forces. While Pact forces are equipped to resist attack by "conventional" tactical nuclear weapons, there appears to be no way at present to protect Pact troops from enhanced radiation weapons. In terms of the costs to NATO of such weapons utilization, it is already clear that the potential costs of such use could be relatively less than for other alternatives. Existing evidence indicates that the number of lives lost and property destroyed could be significantly reduced, yielding a significant change in the deterrence calculation, and making the use of such a weapon more desirable in the event of hostilities.

Clearly, both weapons systems examples would serve to reduce the Warsaw Pact's payoff from a first strike. If this were the only effect, the net

result would be a further stabilization of the existing deterrence situation. The introduction of such systems, however, would also increase the potential payoff to NATO for a first strike, since such an attack is more likely to be successful than was previously the case, and at a reduced cost. Similarly, the potential payoff that the Warsaw Pact would realize as the victim of such an attack would be reduced.

Whether deterrence is, in fact, stabilized will heavily depend on the perceptions which the Warsaw Pact leadership in general, and particularly the Soviets, has as to the extent of the increase in the payoff to NATO for a first strike, and the resulting increase in the probability that NATO would prefer to launch such an attack. If these increases are perceived as being small, or relatively insubstantial, deterrence will have been significantly stabilized. If, however, it is perceived that the introduction of these systems sharply increases the payoff to NATO from a possible first strike, and therefore the probability of such an event, the Pact reaction in a crisis situation may well be to undertake a preemptive first strike at the strategic level.

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APPENDIX A

Preference Ordering I

$U(O_1) = 1, \ U(O_2) = k_2, \ U(O_3) = 0$

$EU(A_1) = k_2$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_1|A_2)$

or

$EU(A_2) = 1/(b-a) \int_a^b U(L)dL .$

Then for the risk adverse (RAV) decision maker:

$k_2 > 1/(b-a) \int_a^b U(L)dL$

and

$\lim_{[a;b] \to 0} EU(A_2) = k_2 \qquad$ or $\lim_{R(L) \to +\infty} EU(A_2) = k_2$

and

$0 < \lim_{[a;b] \to 1} EU(A_2) = \int_0^1 U(L)dL < k_2 \quad$ or $\lim_{R(L) \to 1} EU(A_2) = \int_0^1 U(L)dL < k_2 .$

And for the risk acceptant (RAC) decision maker:

$1/(b-a) \int_a^b U(L)dL > k_2$

and

$\lim_{[a;b] \to 0} EU(A_2) = k_2 \qquad$ or $\qquad \lim_{R(L) \to +\infty} EU(A_2) = k_2$

and

$\lim_{[a;b] \to 1} EU(A_2) = \int_0^1 U(L)dL > k_2 \quad$ or $\lim_{R(L) \to 1} EU(A_2) = \int_0^1 U(L)dL > k_2$

Preference Ordering II

$U(O_1) = 1, \ U(O_2) = 0, \ U(O_3) = 0$

$EU(A_1) = 0$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_1|A_2)$

or

$EU(A_2) = 1/(b-a) \displaystyle\int_a^b U(L)dL \ .$

Then for the risk adverse (RAV) decision maker:

$\lim_{[a;b] \to 0} EU(A_2) = PR(O_1|A_2)$

or

$\lim_{R(L) \to +\infty} EU(A_2) = PR(O_1|A_2)$

and

$\lim_{[a;b] \to 1} EU(A_2) = \displaystyle\int_0^1 U(L)dL > PR(O_1|A_2)$

or

$\lim_{R(L) \to 1} EU(A_2) = \displaystyle\int_0^1 U(L)dL > PR(O_1|A_2) \ .$

And for the risk acceptant (RAC) decision maker:

$\lim_{[a;b] \to 0} EU(A_2) = PR(O_1|A_2)$

or

$\lim_{R(L) \to +\infty} EU(A_2) = PR(O_1|A_2)$

and

$$0 < \lim_{[a;b] \to 1} EU(A_2) = \int_0^1 U(L)dL < PR(O_1|A_2)$$

or

$$\lim_{R(L) \to 1} EU(A_2) = \int_0^1 U(L)dL < PR(O_1|A_2)$$

Preference Ordering III

$U(O_1) = 1, \quad U(O_2) = 1, \quad U(O_3) = 0$

$EU(A_1) = 1$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_1|A_2)$

or

$$EU(A_2) = 1/(b-a) \int_a^b U(L)dL \text{ and}$$

the limits are the same as for preference ordering II.

Preference Ordering IV

$U(O_1) = 1, \quad U(O_2) = 0, \quad U(O_3) = k_3$

$EU(A_1) = 0$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_1|A_2) + PR(O_3|A_2) \times k_3$

$\qquad = PR(O_1|A_2) + (1 - PR(O_1|A_2) \times k_3$

or

$$EU(A_2) = 1/(b-a) \int^b U(L)dL \quad \text{and}$$

the limits are the same as those for preference ordering II, except that the ex-

pression $[PR(0_1|A_2) + (1-PR(0_1|A_2)) \times k_3]$ must be substituted for $PR(0_1|A_2)$.

Preference Ordering V

$U(0_1) = 1$, $U(0_2) = 0$, $U(0_3) = 1$

$EU(A_1) = 0$

$EU(A_2) = 1$

Preference Ordering VI

$U(0_1) = k_1$, $U(0_2) = 0$, $U(0_3) = 1$

$EU(A_1) = 0$

$EU(A_2)$ = $PR(0_1|A_2) \times U(0_1) + PR(0_3|A_2) \times U(0_3)$

       = $PR(0_1|A_2) \times k_1 + PR(0_3|A_2)$

       = $PR(0_1|A_2) \times k_1 + (1-PR(0_1|A_2))$

or

$EU(A_2) = 1/(b-a) \int_a^b U(L)dL$ and

the limits are the same as those for preference ordering II, except that the

expression $[PR(0_1|A_2) \times k_1 + (1-PR(0_1|A_2))]$ must be substituted for $PR(0_1|A_2)$.

Preference Ordering VII

$U(0_1) = 0$, $U(0_2) = 0$, $U(0_3) = 1$

$EU(A_2) = 0$

$EU(A_1)$ = $PR(0_1|A_2) \times U(0_1) + PR(0_3|A_2) \times U(0_3)$

       = $PR(0_3|A_2)$

       = $1-PR(0_1|A_2)$

or

$$EU(A_2) = 1/(b-a) \int_a^b U(L)dL \quad \text{and}$$

the limits are the same as those for preference ordering II, except that the expression $[1-PR(O_1|A_2)]$ must be substituted for $PR(O_1|A_2)$.

Preference Ordering VIII

$U(O_1) = 0, \quad U(O_2) = k_2, \quad U(O_3) = 1$

$EU(A_1) = k_2$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_3|A_2)$

$\qquad = 1-PR(O_1|A_2)$

or

$$EU(A_2) = 1/(b-a) \int_a^b U(L)dL \quad \text{and}$$

the limits are the same as for preference ordering I.

Preference Ordering IX

$U(O_1) = 0, \quad U(O_2) = 1, \quad U(O_3) = 1$

$EU(A_1) = 1$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_3|A_2)$

$\qquad = 1 - PR(O_1|A_2)$

or

$$EU(A_2) = 1/(b-a) \int_a^b U(L)dL \quad \text{and}$$

the limits are the same as those for preference ordering II, except that the expression $[1-PR(O_1|A_2)]$ must be substituted for $PR(O_1|A_2)$.

Preference Ordering X

$U(O_1) = 0$, $U(O_2) = 1$, $U(O_3) = k_3$

$EU(A_1) = 1$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_3|A_2) \times k_3$

$\qquad = (1-PR(O_1|A_2)) \times k_3$

or

$EU(A_2) = 1/(b-a) \displaystyle\int_a^b U(L)dL$ and

the limits are the same as those for preference ordering II, except that the expression $[1-PR(O_1|A_2)) \times k_3]$ must be substituted for $PR(O_1|A_2)$.

Preference Ordering XI

$U(O_1) = 0$, $U(O_2) = 1$, $U(O_3) = 0$

$EU(A_1) = 1$

$EU(A_2) = 0$

Preference Ordering XII

$U(O_1) = k_1$, $U(O_2) = 1$, $U(O_3) = 0$

$EU(A_1) = 1$

$EU(A_2) = PR(O_1|A_2) \times U(O_1) + PR(O_3|A_2) \times U(O_3)$

$\qquad = PR(O_1|A_2) \times k_1$

or

$EU(A_2) = 1/(b-a) \displaystyle\int_a^b U(L)dL$ and

the limits are the same as those for preference ordering II, except that

the expression $[PR(O_1|A_2) \times k_1]$ must be substituted for $PR(O_1|A_2)$.

Preference Ordering XIII

$U(O_1) = 1$, $U(O_2) = 1$, $U(O_3) = 1$

$EU(A_1) = 1$

$EU(A_2) = 1$

APPENDIX B

Preference Ordering I

$$U(V) = 1, \quad U(SQ) = k_2, \quad U(D) = 0$$

$$EU(A_2) = k_2$$

$$EU(A_2) = PR(V|A_2) \text{ or } 1/(b-a)\int_a^b U(L)dL$$

Preference Ordering II

$$U(V) = 1, \quad U(SQ) = 0, \quad U(D) = 0$$

$$EU(A_1) = 0$$

$$EU(A_2) = PR(V|A_2) \text{ or } 1/(b-a)\int_a^b U(L)dL$$

Preference Ordering III

$$U(V) = 1, \quad U(SQ) = 1, \quad U(D) = 0$$

$$EU(A_1) = 1$$

$$EU(A_2) = PR(V|A_2) \text{ or } 1/(b-a)\int_a^b U(L)dL$$

Preference Ordering IV

$$U(V) = 1, \quad U(SQ) = 0, \quad U(D) = k_3$$

$$EU(A_1) = 0$$

$$EU(A_2) = PR(V|A_2) + (1-PR(V|A_2)) \times k_3 \quad \text{or} \quad 1/(b-a)\int_a^b U(L)dL$$

Preference Ordering V

$$U(V) = 1, \quad U(SQ) = 0, \quad U(D) = 1$$

$$EU(A_1) = 0$$

$$EU(A_2) = 1$$

Preference Ordering VI

$U(V) = k_1$, $U(SQ) = 0$, $U(D) = 1$

$EU(A_1) = 0$

$EU(A_2) = PR(V|A_2) \times k_1 + (1-PR(V|A_2))$ or $1/(b-a) \int_a^b U(L)dL$

Preference Ordering VII

$U(V) = 0$, $U(SQ) = 0$, $U(D) = 1$

$EU(A_1) = 0$

$EU(A_2) = 1 - PR(V|A_2)$ or $1/(b-a) \int_a^b U(L)dL$

Preference Ordering VIII

$U(V) = 0$, $U(SQ) = k_2$, $U(D) = 1$

$EU(A_1) = k_2$

$EU(A_2) = 1-PR(V|A_2)$ or $1/(b-a) \int_a^b U(L)dL$

Preference Ordering IX

$U(V) = 0$, $U(SQ) = 1$, $U(D) = 1$

$EU(A_1) = 1$

$EU(A_2) = 1 - PR(V|A_2)$ or $1/(b-a) \int_a^b U(L)dL$

Preference Ordering X

$U(V) = 0$, $U(SQ) = 1$, $U(D) = k_3$

$EU(A_1) = 1$

$EU(A_2) = (1-PR(V|A_2)) \times k_3$ or $1/(b-a) \int_a^b U(L)dL$

Preference Ordering XI

$U(V) = 0$, $U(SQ) = 1$, $U(D) = 0$

$EU(A_1) = 1$

$EU(A_2) = 0$

Preference Ordering XII

$U(V) = k_1$, $U(SQ) = 1$, $U(D) = 0$

$EU(A_1) = 1$

$EU(A_2) = PR(V|A_2) \times k_1$ or $\frac{1}{(b-a)} \int_a^b U(L) dL$

Preference Ordering XIII

$U(V) = 1$, $U(SQ) = 1$, $U(D) = 1$

$EU(A_1) = 1$

$EU(A_2) = 1$

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